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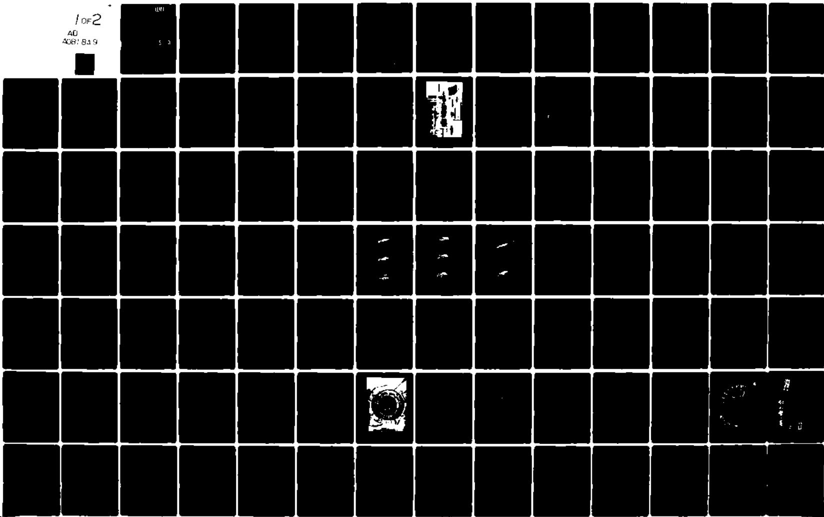

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(2) LEVEL III

AFAPL-TR-79-2123

BUILD 3 OF AN ACCELERATED MISSION TEST OF A TF41 WITH BLOCK 76 HARDWARE

PERFORMANCE BRANCH
TURBINE ENGINE DIVISION

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TECHNICAL REPORT AFAPL-TR-79-2123
Final Report for Period 27 November — 13 December 1978

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AIR FORCE AERO PROPULSION LABORATORY
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This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An accelerated mission test (AMT) of a TF41 (S/N 142163) was conducted in the Air Force Aero Propulsion Laboratory's "D" bay sea-level engine test faciltiy. The primary objective of the test was to evaluate the structural reliability of a series of parts changes known as "Block 76" hardware. This was the last in a series of 3 scheduled tests. A two hundred sixty-three hour test program was initially planned but only one hundred thirty-three hours were actually completed due to the failure of a first stage low pressure compressor stop plate. Post-test

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teardown showed all of the "Block 76" hardware to be in good condition. Engine performance deterioration was tracked and an exhaust gas temperature survey was performed and the data analyzed. This report describes the details of the test, including test objectives, approach, instrumentation, facility and results.

FOREWORD

This report describes an in-house test conducted by personnel of the Turbine Engine Division and Technical Facilities Division, Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio, under Project 3066, Task 16, Work Unit 02.

The work reported herein was performed during the period 27 November to 13 December 1978 under the direction of the project engineer, Robert J. May, Jr. (AFAPL/TBA).

The author wishes to thank the technicians involved for their hard work in this program, especially Messrs Richard G. Homer, Paul R. Hagedorn, Jerrold F. Carnes, Leroy P. Sauer, Donald J. Perdzock, and Robert Graf. Special mention goes to Mr Mark Reitz for his aid in data reduction and report preparation. The author also wishes to express his thanks to Detroit Diesel Allison Division of General Motors, especially Mr Darwin Hoose and Mr Gary Williams for their patience and assistance.

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SECTION I
INTRODUCTION

This report describes an Accelerated Mission Test (AMT) of a Detroit Diesel Allison TF41-A-1 turbofan engine, S/N 142163. The primary objective of this test was to evaluate the structural reliability under realistic usage conditions of a series of structural improvements known as "Block 76" hardware (Table 1). Two hundred sixty-three hours of AMT testing were initially scheduled for this engine build. However, the test was terminated after only 133 hours due to the failure of a first stage low pressure compressor stop plate. The test was conducted between 27 November and 13 December 1978 in the Air Force Aero Propulsion Laboratory's D-Bay sea level engine test facility.

This test was conducted as part of a fleet leader program which also included flight test of this engine configuration by both the Navy and Air Force. This was the third AMT test of this serial number engine. The initial test ended after only 106 hours due to a failure in the second stage high pressure turbine (Ref 1). The engine was rebuilt and completed 189 test hours before a failed first stage high pressure turbine blade terminated the test (Ref 2). The initial failure of this engine damaged the cast first stage high pressure turbine blades which were part of the "Block 76" package. Sufficient replacement cast blades could not be located so the standard production blades were used. In addition to the "Block 76" hardware, this test was used to verify the durability of an experimental set of aircooled second stage high pressure turbine blades. A similar set of blades had been run in a TF41 performance test at AEDC and an earlier design of the aircooled blade was run in an AMT test at AFAPL (Ref 3).

TABLE 1

"BLOCK 76" HARDWARE

PART	PURPOSE
HPT #6 cast bearing support	Ease of Assembly and Reduced Oil Consumption
HPT - 1 cast blade	Reduce cost
HPT - 1 bullnose vane	Obtain 500 hour hot section life
#5 bearing rear seal	Deletes seal requirement
HPC-4-5-6 Eiffel tower vanes	Improve fatigue strength
HPC - 1 full chord blade	Improve surge margin
8-9 fuel manifold	Improve temperature profile
NL anticipator	Reduce turbine inlet temperature spikes
HPT - 1 lockplate damper	Reduce fretting
Viton Wills ring	Reduce oil consumption

SECTION II
TEST OBJECTIVES

OBJECTIVE 1: Establish durability and operability characteristics of a TF41 with "Block 76" hardware modifications under realistic usage conditions.

In the past, several TF41 fixes and modifications were introduced into the fleet without proper testing and evaluation. These hastily adopted fixes, in addition to not solving the problems they were intended to, have resulted in unexpected interactions which have caused failures in other components. By the time these problems surface, the entire fleet has been retrofit and the purging process is time-consuming and causes related nontechnical problems. According to the 1975 TF41 Executive Review Group Report (Ref 4), "this issue can be resolved by designing proper test programs to prove the improved parts are really improved." The report further states that the consequence of the proposed fixes should be demonstrated in the context of the total engine and under realistic usage conditions. This test objective is aimed at meeting this ERG recommendation by running a production TF41, modified with the proposed "Block 76" hardware, through a test program which is representative of the type of usage that the engine will see in the field. The "Block 76" hardware modifications and their purpose are described in Table 1.

OBJECTIVE 2: Demonstrate the durability of various overhaul repair schemes under realistic usage conditions.

During overhaul of the TF41's at both Air Force and Navy facilities, it is often necessary and desirable to "repair" or "rework" some parts rather than to replace them with new ones. In keeping with the 1975 TF41 Executive Review Group's mandate that "there must be very careful testing and verification of the adequacy of repair procedures especially for the critical hot section of the engine," some rework schemes were incorporated in this engine to verify their reliability.

The specific rework schemes included in the build-up of this engine are:

- 10 first stage low pressure compressor blades with weld repaired clappers

- 15 first stage low pressure compressor blades with hardcoat replacement
- 5 combustion liners repaired with "L605" rings
- 10 primary combustor air scoops with weld repairs
- Discharge nozzle mounting nut ground off
- #7 bearing housing repair scheme
- first and second stage low pressure turbine blades with repaired shrouds

In addition, several new or modified parts were also tested including:

- H.P. fuel pump with Viton HMG diaphram
- Viscoelastic wrapped inlet extension
- Oil filter/relief valve modification to oil pump
- 4 x 5 discharge nozzle

OBJECTIVE 3: Document overall engine performance deterioration.

The 1974 TF41 Executive Review Group (Ref 5) listed engine thrust deterioration as a problem area. However, the engines in the field have been seeing less than 200 hours of use before overhaul due to assorted durability problems. In this relatively short amount of time, the engines have not deteriorated to the point of causing a problem. However, many of the CIP objectives, including the "Block 76" hardware modifications, are aimed at improving engine life to the point where the TF41 is a "firm 1000 hour MOT engine with a 500 hour hot section periodic inspection." Under these conditions, deterioration is expected to become a problem. A recent TF41 Management Review Group established engine thrust deterioration as a prime area of concern.

Some deterioration data has been generated by past AEDC tests of TF41s. However, the engines did not have the "Block 76" hardware modifications which may impact the engine's deterioration characteristics. More importantly, due to the nature of the test objectives, most of the AEDC engine's test time was at steady-state conditions. However, due to the many transients imposed on the engine in the A7 aircraft, the AEDC engine's deterioration would not be totally representative of the deterioration that an engine would exhibit after an equivalent number of hours in operational usage. The

deterioration data from this type of accelerated mission test should be more representative of field usage and its effects on engine deterioration.

OBJECTIVE 4: Investigate burner outlet temperature profile changes as the engine deteriorates.

One of the major causes of first stage turbine nozzle failure in the TF41 has been the high peak burner outlet temperatures encountered both transiently and at steady-state conditions. Several changes have been made in the combustor and control to reduce these peak temperatures. However, the impact of combustor deterioration and deterioration in the upstream compression components on burner peak temperature is an area where little data has been generated. In fact, the 1975 TF41 Executive Review Group recommended that AMT "testing should include periodic traverse measurements as a function of cycle time to account for combustor performance degradation" (Ref 4).

The best method for accomplishing this objective and the one recommended by the 1975 ERG is to install high pressure turbine nozzle vane leading edge instrumentation. However, discussion with NAPTC personnel at Trenton, where this approach was used in a performance test, revealed that the vane instrumentation is so delicate that it is inapporpriate for AMT type of testing. The instrumented vanes would have to be removed while the cyclic testing was being conducted and then reinstalled to take a temperature profile measurement at different time intervals throughout the test. This would result in unacceptable time delays and also the Navy's experience showed that continued removal and reinstallation of this instrumentation resulted in an unacceptably large number of thermocouple failures.

An alternate approach would be to measure the turbine exhaust gas temperature profile and at least qualitatively relate it to the turbine inlet temperature profile. A 45 thermocouple rake was fabricated to fit in the TF41 tailpipe which allowed mapping of the exhaust gas temperature profile during the steady-state power calibration portions of the test and was easily removable for cyclic testing.

OBJECTIVE 5: Establish the durability characteristics of a set of TF41 aircooled second stage turbine blades under realistic engine operating conditions.

Allison is proposing to incorporate an aircooled blade into the second stage turbine (HPT-2) of the TF41 as part of a program to extend the hot section life. The present HPT-2 blades have suffered from thermal fatigue failures of the airfoil and low cycle fatigue (or possible high cycle fatigue) in the blade and disk serration. The current blades have estimated design lives of 1000 hours. The cooled blade is estimated to have a design life of 3000 hours.

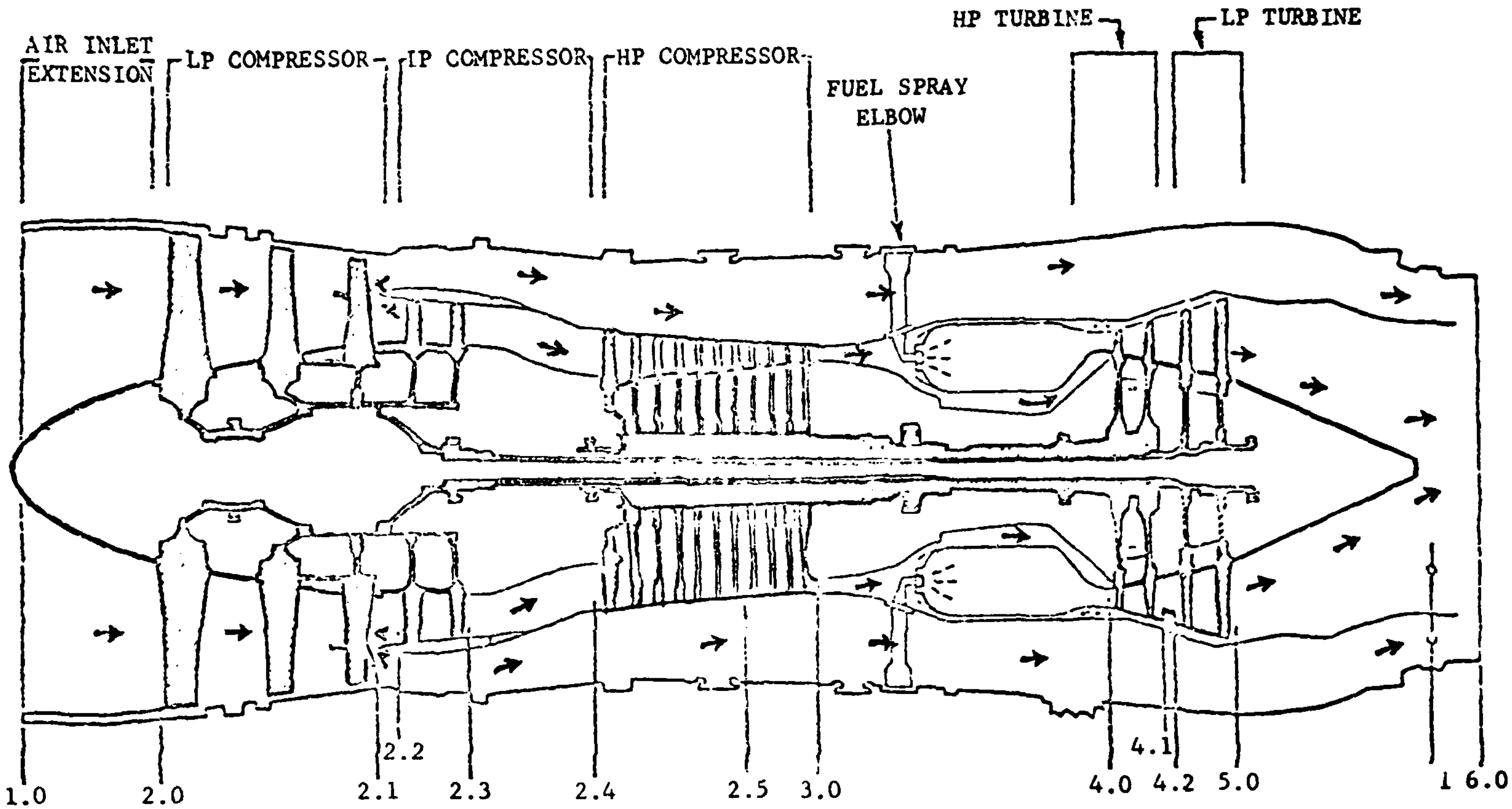
One of the major criticisms of both the 1974 and 1975 TF41 Executive Review Groups (Ref 4 and 5) was that the lives (especially low cycle fatigue life) of many engine parts are not well established. This objective addresses this criticism by attempting to establish the life of the new HPT-2 blades in a realistic engine environment before they are retrofit into the fleet.

As part of the aircooled turbine package, first stage low pressure turbine vanes with cutback leading edges, and second stage high pressure turbine blades with reduced shroud gaps were included.

SECTION III
ENGINE DESCRIPTION

The TF41-A-1 is a mixed flow turbofan engine manufactured by Detroit Diesel Allison Division of General Motors and is currently used to power the Air Force and Navy's A7 aircraft. The engine is a twin spool design with a three-stage low pressure compressor driven by a two-stage low pressure turbine. The core engine consists of a two-stage intermediate pressure compressor also driven by the low pressure turbine and an 11-stage high pressure compressor with variable inlet guide vanes driven by a two-stage high pressure turbine. In the production version, first and second stage vanes and the first stage blades of the high pressure turbine are aircooled. The main burner is an axial flow design incorporating ten cannular combustion chambers. The core engine exhaust gas and the bypass air are mixed downstream of the low pressure turbine and exhausted out a fixed area convergent nozzle. The engine is shown schematically in Figure 1.

The TF41 has a design (sea level static, standard day, intermediate power) airflow of 261 lb/sec, a design bypass ratio of .7, a design fan pressure of 2.45 and a design overall pressure ratio of approximately 22. The maximum turbine inlet temperature is estimated at approximately 2625°R. The engine is rated at 14,500 lb of thrust at sea level static standard day conditions with a specific fuel consumption of .654.



1.0 Engine Inlet
2.0 LP Compressor Inlet
2.1 Bypass Duct Inlet
2.2 IP Compressor Inlet
2.3 IP Compressor Outlet

2.4 HP Compressor Inlet
2.5 Seventh Stage Bleed Outlet
3.0 HP Compressor Outlet
4.0 HP Turbine Inlet
4.1 HP Turbine Outlet

4.2 LP Turbine Inlet
5.0 LP Turbine Outlet
5.1 Measured Gas Pressure and Temperature Station
6.0 Engine Outlet

FIGURE 1 - TF41 ENGINE SCHEMATIC

SECTION IV
FACILITY DESCRIPTION

This AMT test was conducted in the Air Force Aero Propulsion Laboratory's "D"-Bay sea level engine test facility, located in Building 71A at Wright-Patterson Air Force Base, Ohio. The cell is a conventional "U" shaped configuration with a 50 foot by 50 foot cross section test area.

"D"-Bay's thrust bed is rectangular in shape and utilizes a hinge type flexure at each corner. The maximum thrust load rating is 60,000 pounds and is measured via an Ormand, constant temperature load cell. The load cell is capable of measuring both forward and reverse thrust.

Test cell air is drawn down vertically through the inlet and then passes through a set of turning vanes and a large mesh bird screen. Behind the engine, air is processed down an 11' diameter test cell augmentor and blast suppressor entering a large square plenum chamber. Located directly above the plenum chamber is a large vertical chimney which contains 42 tubular shaped mufflers for suppressing the noise level of the exhaust flow. The test cell airflow design point is 2300 pounds per second with less than five inches of water inlet pressure drop. Higher airflows are possible, assuming greater inlet depression is acceptable. Water cooling in the exhaust stack is available if required and the augment tube will traverse, providing the capability for adjustment of the augmentor to tailpipe distance.

Fuel is stored in the AFAPL centralized Fuel Farm. Nearly 800,000 gallons are stored in 32-25,000 gallon tanks. The test cell fuel system can accommodate a flow rate in excess of 100,000 pounds per hour. The system is also designed to provide a 100,000 pounds per hour per second transient flow rate capability. Fuel inlet pressure can be adjusted over a range from 0 to 100 psig.

Starting air is supplied by three Ingersol-Rand, Pac-Air 3000 compressors. These will generate approximately 5.4 pounds per second total flow rate at pressures up to 100 PSIG.

The entire "D"-Bay test facility and the test engine are controlled by a Taylor 1010/72 process control computer. The 1010 is a direct digital control (DDC), real time processor which interfaces with the engine and

facility through a series of analog and digital inputs which provide the computer with the information necessary to regulate, control, and optimize all phases of the "D"-Bay operation. The system in "D"-Bay is redundant with two identically configured process control computers connected together with a high speed memory link. A "bus switch" is used to allow the input and output lines to be rapidly switched to the backup computer in the event of a primary computer failure. In addition to the control function, the Taylor 1010 and its peripheral equipment provide "D"-Bay's primary means for acquiring and displaying data. A Modcomp II-26 computer was linked to the Taylor system and provides the means for data storage. Approximately 76 variables (engine and facility) as well as the output from all facility devices (i.e., pumps, valves, etc.) were acquired and stored at the rate of once per second.

Engine throttle control is provided by an ATEC throttle control unit. Throttle actuation is accomplished electrically through a buffer/transmitter-stepper drive motor, receiving commands from the electronic logic package located in the control room. Pre-set or variable actuation rates may be used or the throttle may be manually moved via a "joy stick" actuator. Throttle movements can be made manually or the throttle system can be interfaced with the computer to automatically reproduce any input throttle profile.

A picture of the facility with the TF41 installed is shown in Figure 2. A more detailed description of the facility and the computer can be found in reference 1.

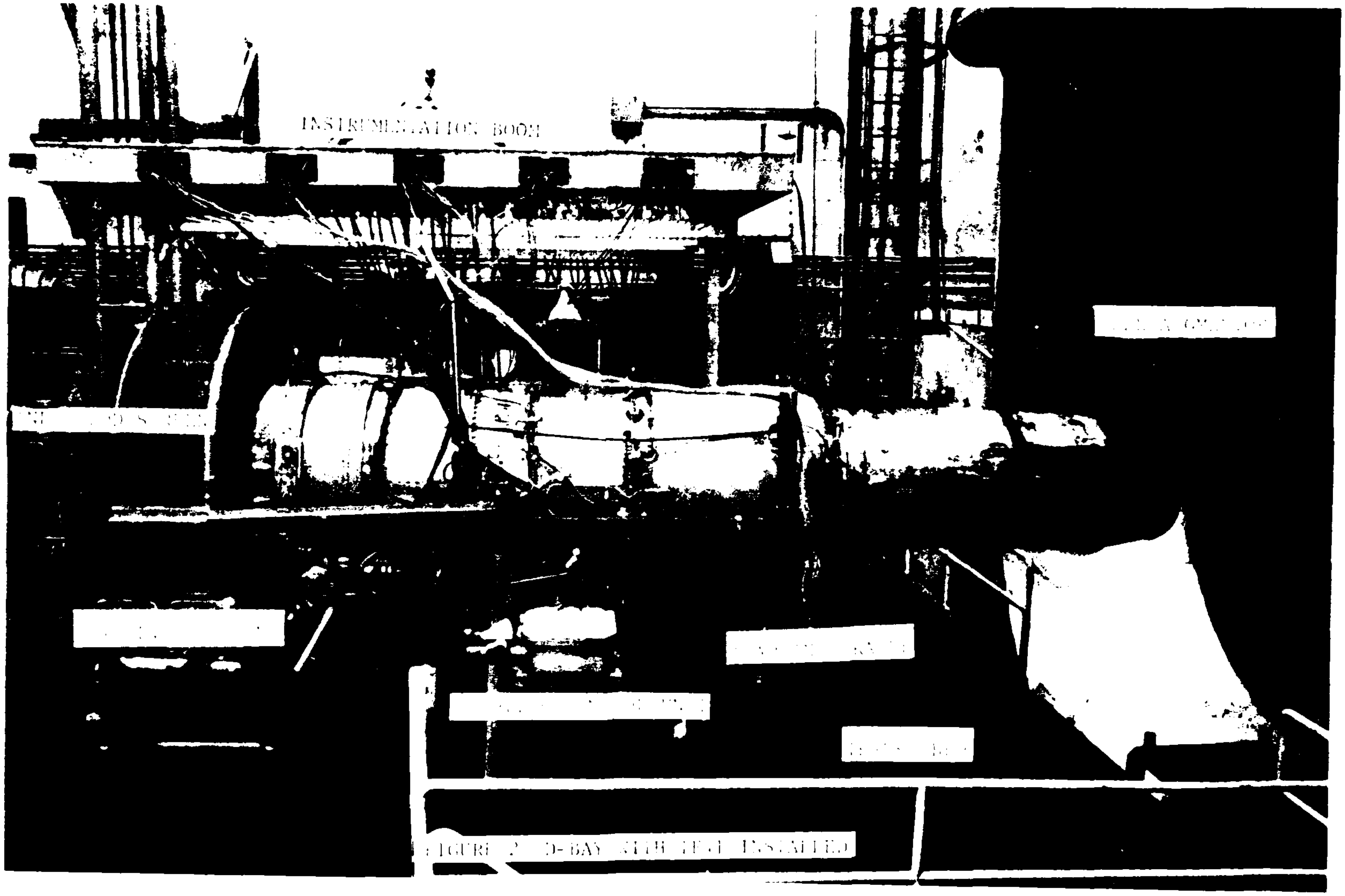


FIGURE 2 D-BAY WITH TEST INSTALLED

SECTION V
TEST CYCLES

Figures 3, 4, and 5 graphically represent the throttle transient profiles run during the test. Percent of design high pressure compressor rotational speed is plotted versus time. These cycles were programmed into the control computer, making use of the high pressure compressor speed, power lever angle relationship for this engine which was generated during the power calibration portion of this test. This is required because the automatic throttle controls power lever angle rather than compressor speed.

The cycle depicted in Figure 3 is designated the Flight cycle (also referred to as an "A" cycle) and is representative of the actual flight usage that the TF41's are seeing in the field. This cycle lasts 43 minutes and 29 seconds. It consists of a considerable number of engine accels and decels as well as a significant amount of time at maximum power. Figure 4, graphically depicts a Start cycle (also referred to as a "B" cycle) representative of flight line maintenance operation. Each "B" cycle includes 10 minutes and 30 seconds of engine operation and contains three engine starts and the remaining time at idle power. Figure 5 is a so-called Ground cycle (also referred to as a "C" cycle) which reproduces typical test cell and trim pad operation. This cycle lasts two hours, six minutes, and 15 seconds. It is composed of several accels from idle to relatively high power settings, followed by steady state operation at this condition, and then a decel to idle.

A complete TF41 AMT test consists of 15+ blocks of testing which is approximately 263 hours of operation. Each block is made up of 20 "A" cycles, four "B" cycles, and one "C" cycle. A complete tabulation of the steps in each cycle may be found at the back of the test plan, Appendix D.

This combination of cycles is representative of the type of usage that a typical TF41 is subjected to in the field. A joint Allison and Air Force project compiled and analyzed data from many sources in order to derive these throttle profiles. Navy "Inflight Engine Condition Monitoring System" (IECMS) Data was used to provide records of engine histories during actual flight. An extensive program of pilot interviews

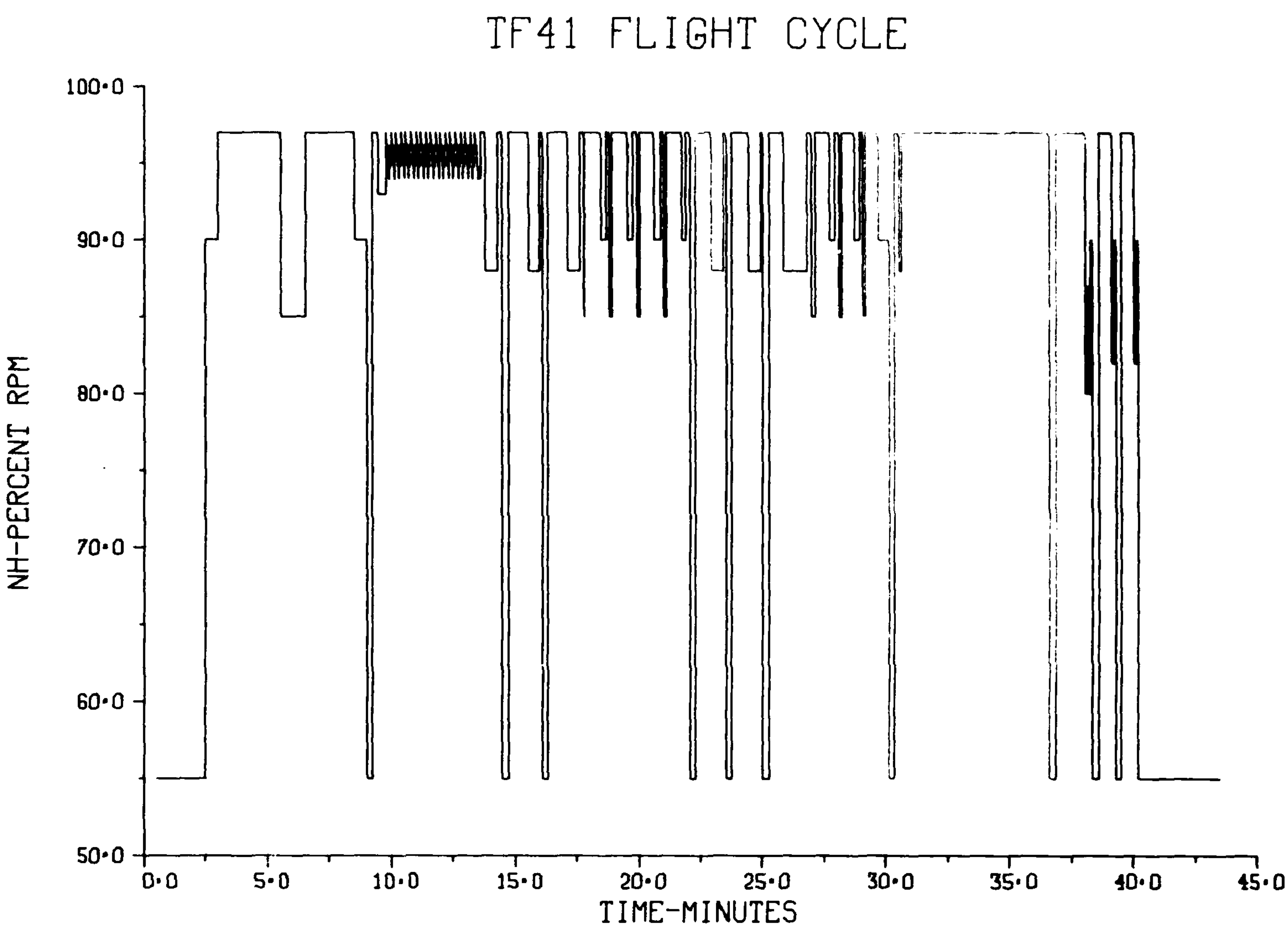


FIGURE 3 TF41 FLIGHT CYCLE

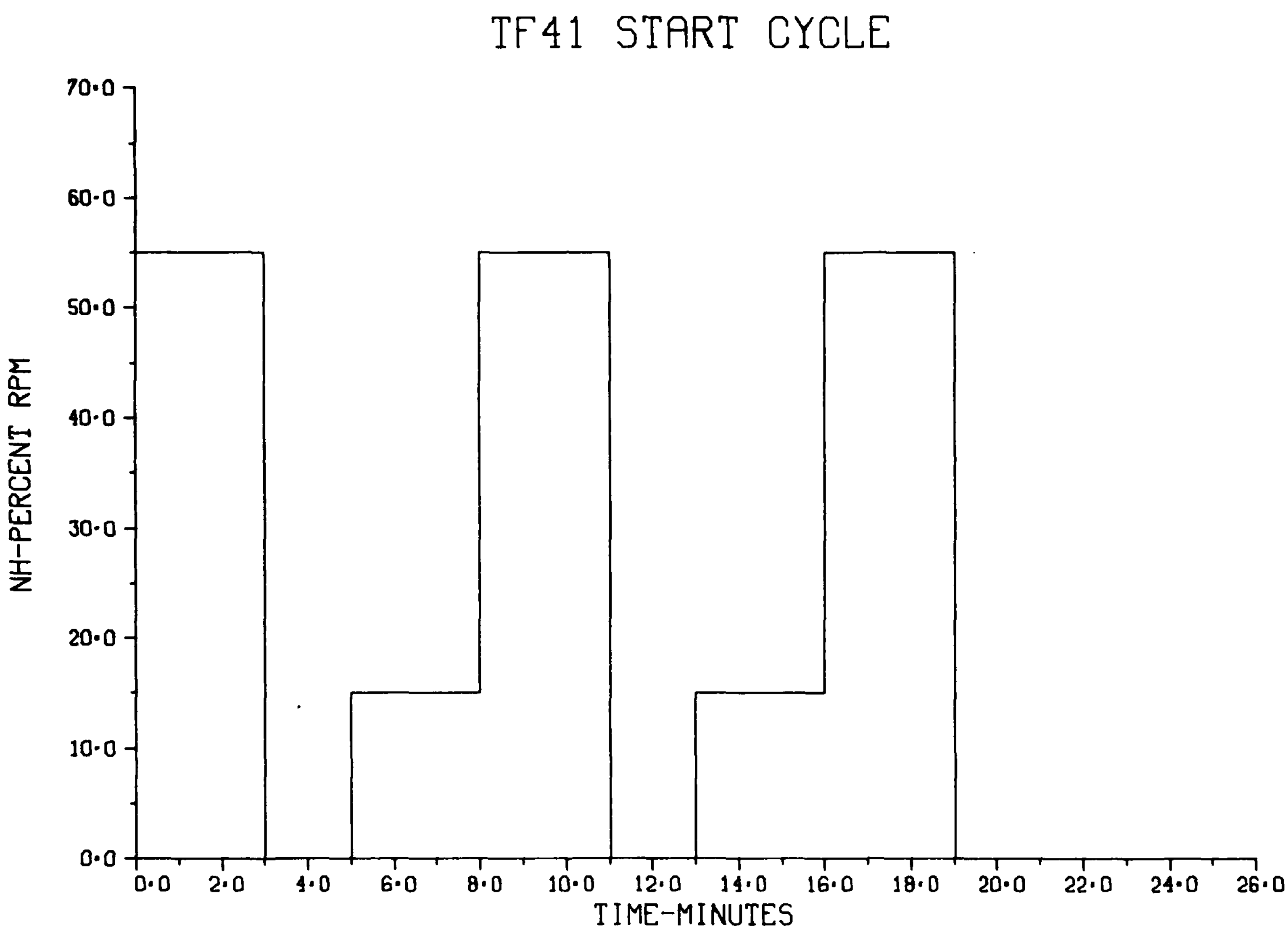


FIGURE 4 - TF41 START CYCLE

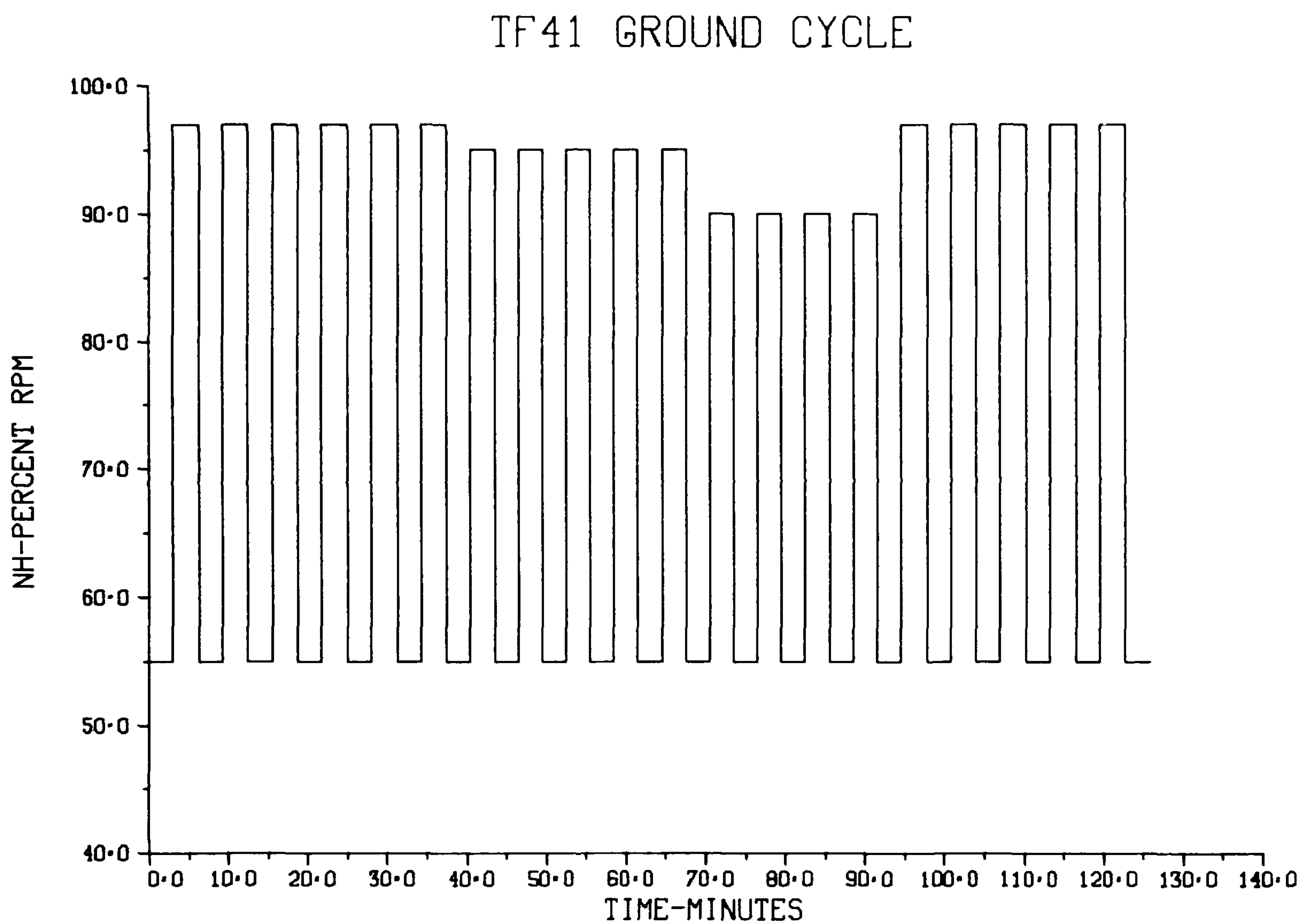


FIGURE 5 - TF41 GROUND CYCLE

was used to determine mission mix, estimates of throttle movement frequency, time at maximum power, effects of flight position (i.e., lead or wingman), mission profile definition (altitude, Mach number, time, weight, configuration), and the effects of pilot experience level. Also a flight test program was run at AFFTC, Edwards AFB CA using specially instrumented engines to define typical ranges of engine parameters during operational flight. Finally, engine data recorded during flight as part of the "Engine/Airframe Structural Integrity Program" (ENSIP/ASIP) was assessed.

All this data was analyzed and used to define the three real time cycles and the proper mix that would directly relate to real engine usage. The non-damaging portions of the cycles (i.e., low power operation and small throttle changes) were eliminated in order to compact the cycles. Thus, one AMT test hour is approximately equivalent to 1.9 flight hours.

SECTION VI
INSTRUMENTATION

All instrumentation located in the test facility, either engine or facility related, passes its signal through a signal conditioning room before being routed to the control computers. This provides a common interface location for all patching, calibrating, and adjusting activities. The signal conditioning room is provided with its own interactive terminal link to the digital control system.

On the engine test deck a signal distribution bus, or engine boom, is cantilevered from the cell wall to provide a hook-up point for all engine data signals. A completely enclosed transducer cabinet also provides for local conversion of pressure signals to 0-5V output. This engine boom is permanently wired into the signal conditioning room and provided with various connectors for pressure, hydraulic, electrical, or thermocouple signals.

The following is a brief description of the current data channel capability:

Temperature Channels. Ninety-six (96), temperature (thermocouple) channels are provided. These channels are complete with all necessary signal conditioning and distributed into 40 Type K, 40 Type J, and 16 Type T couples. An ice point reference junction is provided for each channel in the signal conditioning room. Thermocouple jack panels on the engine boom are provided to facilitate installation.

Pressure Channels. The engine boom contains 68 pressure taps of two different types. Sixty of the taps are fitted with Tomco quick disconnect fittings and are limited to 500 psig (by the disconnect) and the other eight are fitted with ordinary pipe fittings for high pressure hydraulic lines. A heated, enclosed cabinet is positioned on the engine deck for the mounting of transducers, thus limiting the distance the actual pressure signal must traverse. Each channel of pressure must be equipped with a signal conditioner/transducer to provide a 0-5V output linear over the range of pressure to be measured. Cables to support these signals are provided from the engine deck to the signal conditioning room. A signal patch panel then provides a permanent path to the digital control system in the control room.

Undesignated Channels. There are 32, 0-5V input channels which are currently undesignated. These are provided with a Mil-Std, five pin connector at the engine boom. These connectors are then provided with a signal cabling to the signal conditioning room and can be connected to the digital control system through a patch panel.

These channels are used to support signals from speeds, vibrations, flow-rates, positions, etc. The software which stipulates the parameters of the measured variable allows a change to be made in the designation via a keyboard entry from the control system, CRT terminal.

Engine Instrumentation. The following is a list of the primary engine related instrumentation which was available and operative during this test of TF41 S/N 142163. All the instrumentation was displayed as a digital output on a cathode ray tube (CRT) display which was updated continuously once per second. Hard copy data was recorded, as required, automatically using a line printer at the rate of once per minute. In addition, all engine parameters were stored on disk (at a once per second rate) using the Modcomp II computer. Finally, 16 channels of oscillograph recorder were available to continously record some of the more important engine parameters.

1. Engine inlet total temperature (°F) - the average of three iron-constantan thermocouples located in the air inlet bellmouth. The accuracy of this reading is ±1°F.

2. Engine inlet total pressure (PSIA) - the average of three total pressure probes located in the air inlet bellmouth. The accuracy of this reading is ±.01 PSIA.

3. Inlet static pressure (PSIA) - the average of three static pressure taps located in the air inlet bellmouth. The accuracy of this reading is ±.01 PSIA.

4. Low pressure compressor rotor speed (% Design RPM) - from an engine furnished tachometer on the L.P. gearbox. The accuracy of this reading is ±.2%. In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

5. High pressure compressor rotor speed (% Design RPM) - from a test equipment tachometer mounted on the H.P. gearbox. The accuracy of this reading is ±.1%. In addition to the CRT display, it is continuously recorded on an Offner oscillograph recorder.

6. Turbine outlet temperature (°F) - from nine engine furnished chromel-alumel thermocouples connected in parallel and electronically averaged. The accuracy of this reading is ±4°F. In addition to the CRT display, it is also recorded continuously on an Offner oscillograph recorder.

7. Fuel flow (LB_M/HR) - from a test cell furnished flow meter located in the fuel supply line to the engine. The range of this meter is 0-11,000 LB_M/HR. The accuracy of this reading is ±.5%. In addition to the CRT display, it is continuously recorded on an Offner oscillograph recorder in the control room.

8. Fuel inlet temperature (°F) - from a closed-tip type iron-constantan thermocouple located in the test stand fuel line near the flow meter. The accuracy of this measurement is ±1°F.

9. High pressure compressor discharge static pressure (PSIG) from a static pressure tap located on the number nine strut in the diffuser. The measurement is from an engine furnished fitting on the fuel control sense line. The accuracy of this measurement is ±.05 PSI.

10. High pressure compressor discharge temperature (°F) - from two engine furnished chromel-alumel thermocouples located in numbers three and nine fuel nozzles and averaged. The accuracy of this reading is ±1°F.

11. Fuel manifold pressure (PSIG) - from a pressure tap on the fuel manifold on the left side of the engine. The accuracy of this measurement is ±1%. In addition to the CRT display, it was also continuously recorded on an Offner oscillograph recorder.

12. Low pressure turbine discharge total pressure (PSIG) - from nine engine furnished total pressure probes spaced circumferentially in the turbine exhaust. The measurement is picked up from the P5.1 pressure manifold tap. The accuracy of this measurement is ±.1 PSI. In addition to the CRT display it was also continuously recorded on an Offner oscillograph recorder.

13. Engine main oil pressure (PSIG) - from a high pressure fitting on the oil filter. The accuracy of this measurement is ±.5 PSI. In addition to the CRT display, it was also continuously recorded on an Offner oscillograph recorder.

14. Low pressure cooling air discharge temperature (°F) - taken at the jack on the L.P. cooling air duct fitting using an iron-constantan thermocouple. The accuracy of this measurement is ±1°F.

15. Engine vibrations (mils) - measured using type "106" vibration pickups. In addition to the CRT display, it was also continuously recorded on an Offner oscillograph recorder.

- Front compressor (vertical) - mounted on the front flange on top of the engine.
- Rear compressor (vertical) - mounted on the fuel manifold boss on top of the engine.
- Turbine (near vertical) - mounted on the low pressure turbine oil tube boss on the bottom of the engine.

16. IGV position (degrees) - an angle probe mounted on the engine airflow regulator and measures regulator travel in terms of HP inlet guide vane angle.

17. Power lever position (degrees) - measures the total cam-box lever travel. The accuracy of this measurement is ±1°. In addition to the CRT, this parameter is a digital display on the auto-throttle control panel and continuously recorded on an Offner oscillograph recorder.

18. Engine oil inlet temperature (°F) - from a closed tip iron-constantan thermocouple located in the tube to the L.P. turbine bearing. The accuracy of this reading is ±1°F. In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

19. Engine thrust (LB_F) - from load cell deflection. The range of the load cell is -60 to +60 KLBS. The accuracy of this reading is ±100 LBS.

20. Fuel inlet pressure (PSIG) - from a measurement taken near the L.P. fuel pump inlet. The accuracy of this measurement is ±1 PSIG. In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

21. Oil tank temperature (°F) - from a closed tip iron-constantan thermocouple mounted in place of the oil tank drain plug which senses engine oil outlet temperature as measured at the oil tank. The accuracy of the measurement is ±1°F. In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

22. Junction box temperature (°F) - from an iron-constantan thermocouple installed on the small mounting lug for the ballast resistor in the T5.1 thermocouple junction box. The accuracy of this measurement is ±1°F.

23. Pilot fuel manifold pressure (PSIG) - from a pressure tap on the pilot manifold near the main manifold pressure tap. The accuracy of this reading is ±25 PSIG. In addition to the CRT display, it is also continuously recorded on an Offner oscillograph recorder.

24. Temperature limiter amplifier current (Milliamps) - measures current to the main fuel control limiting solenoid. Taken from pins 12 and 13 of amplifier test connector on the temperature limiter amplifier. The accuracy of this measurement is ±.5 milliamps. In addition to the CRT display, it was also continuously recorded on an Offner oscillograph recorder.

25. Ambient pressure (in HG) - from a barometer located on the outside wall of the test cell.

26. Wet bulb temperature (°F) - measurement made periodically in the test cell using a sling psychrometer.

27. Dry bulb temperature (°F) - measurement made periodically in the test cell using a sling psychrometer.

28. Eleventh stage bleed total pressure (PSIA) - from a pressure probe located in the 11th stage compressor customer bleed port. The accuracy of this reading is ±.1 PSIA.

29. Eleventh stage bleed static pressure (PSIA) - from a static tap on the probe located in the 11th stage compressor bleed port. The accuracy of this reading is ±.1 PSIA.

30. Fan discharge total pressure (PSIG) - from a dual pressure probe located in the forward borescope port. The accuracy of this reading is ±.1 PSIG.

31. Intermediate pressure compressor discharge total pressure (PSIG) - the other half of the dual pressure probe located in the forward borescope port. The accuracy of this reading is ±1 PSIG.

32. Fan discharge total temperature (°F) - from a dual probe located in the forward borescope port using a chromel-alumel thermocouple. The accuracy of this reading is ±4°F.

33. Intermediate pressure compressor discharge total temperature (°F) - the other half of the dual probe located in the forward borescope port also using a chromel-alumel thermocouple. The accuracy of this reading is ±4°F.

34. Exhaust gas temperature rake (°F) - a 45 thermocouple rake located directly behind the last stage of turbine. The chromel-alumel thermocouples are mounted on an adapter that fits between the engine case and the tailpipe (see Figure 36). The accuracy of these readings is ±4°F. Each thermocouple is read individually.

SECTION VII
DISCUSSION OF THE TEST

SUMMARY

An accelerated mission test of TF41 (S/N 142163) with "Block 76" hardware was conducted at the Air Force Aero Propulsion Laboratory's sea level engine test facility, D-Bay. A complete accelerated mission test normally consists of 263 endurance hours, made up of 306 "A" cycles, 60 "B" cycles, and 15 "C" cycles. Only 133 endurance hours (148 total operating hours) were completed before a first stage low pressure compressor stop plate failure ended the test. One hundred eighty-three "A" cycles were completed.

ENGINE HISTORY

The original build of 142163 underwent an accelerated mission test in D-Bay and suffered a second stage high pressure turbine blade failure and heavy secondary turbine damage after 106 AMT hours (Ref 1). The engine was rebuilt using the forward section from engine 142163 and the burner and turbine sections from engine 141677 (Ref 2). This build completed 189 more AMT hours before a first stage high pressure turbine blade failed. Including the time accumulated during trim, checkout, and trouble shooting more than 400 hours of operation had been accumulated on the original engine parts of which 295 were AMT hours.

ENGINE RELATED INCIDENTS

In general, up to the stop plate failure, the TF41 engine in this program operated extremely well, with a minimum number of mechanical problems. The more important engine related incidents that occurred during the test are summarized below:

- Defective Oil Scavenge Screen - during the initial engine run after installation in the cell, oil pressure was below limits at idle. The engine was immediately shutdown. A defective oil scavenge screen was discovered which allowed engine oil to be lost overboard. The screen was replaced.

- NL Overspeeds - low pressure rotor speed in excess of 101% were encountered transiently (<.3 sec) during some accels during the first few "A" cycles. This was attributed to a high mass flow limiter setting which was subsequently trimmed back. Thereafter, operation was normal.

- Oil Leak - After approximately 30 AMT hours, a crack was noticed in the mounting base for the oil tank thermocouple which was causing a loss in engine oil. It was repaired.

- Eroded Ignitor Plugs - During the 50 hour inspection it was discovered that the ignitor plugs were eroded beyond T.O. limits. Replacement plugs could not be located so the original plugs were used for the remainder of the test.

- Low Idle Speed - After approximately 80 AMT hours idle RPM (NH) dropped below the T.O. limit of 53%. It was adjusted back into limits.

- Wear Debris - Oil - Periodic ferrographic analysis of the engine oil showed a continuously increasing amount of wear debris. (See Appendix B). This indicated a potential problem with some oil wetted component.

- Broken LPC Stop Plate - Approximately 5 minutes into the 184th "A" cycle on an accel from idle to intermediate, turbine vibration spiked up over 5.0 mils. The control computer shut the engine down immediately. There was no apparent external damage. The H.P. rotor could be turned freely by hand, but the L.P. rotor was seized. After approximately 1 hour the L.P. rotor could also be turned by hand. However, subsequent attempts to operate the engine resulted in high turbine vibrations. The engine was removed from the cell and returned to Allison.

TEST PROCEDURES

Throughout this entire test program, the engine was operated in accordance with the procedures and limits contained in Air Force Tech Order, T.O. 2J-TF41-6 (Ref 6) and Allison Publication Nr 1F2, TF41-A-1 Engine Operation and Service (Ref 7). Prior to each day's running, a pre-test checklist, including a visual inspection of the engine and test cell were completed. Oil level was checked several times during the day and rotor coastdowns were recorded upon the last shutdown of each test period.

A functional check of the engine's limiters, governors, and schedules was performed before the endurance portion of the test and a similar check was planned after every 100 AMT hours of testing. A pre-test steady-state power calibration, between 50% power and maximum power was also carried out. Actually, two steady-state power calibrations were performed back to back. Due to an installation problem, the left side forward borescope port was not accessible so the fan/ID discharge pressure and temperature instrumentation (usually located in the forward borescope ports) could not be run simultaneously. An additional series of steady-state points were run

to define the high pressure compressor rotor speed/power lever angle relationship needed to input the test cycles into the automatic throttle controller. Additional calibrations were scheduled in 100 AMT hour intervals and after completion of the test.

Engine maintenance and inspections were planned at 50 hour intervals according to Allison publication 1F2 (Ref 7). Borescoping of the engine was to be performed after every 100 AMT hours. Oil samples were taken after approximately 25 hours of engine operating time.

During the test operation, all facility and engine instrumentation were monitored by the control computer and by the test operator and the test cell observer using CRT displays. Hard copy data was recorded using the line printer during the six minute constant power level operation at intermediate power (referred to as the "Intermediate Power Flat") which occurs near the end of every "A" cycle and was processed by a data reduction computer program (using methods outlined in Appendix A) after each day's run. Seventy-six engine and facility parameters were recorded and stored on a computer disk at a one per second rate throughout the duration of the test. In addition, 16 channels of oscillograph recorder were available to continuously record some of the more important engine pearameters (See Section VI).

Normally, the endurance portion of an AMT test is run in a series of blocks, each block consisting of 20 "A" cycles, followed by 4 "B" cycles, followed by 1 "C" cycle. However, due to the difficulty in changing cycles in the control computer, this sequencing was not followed.

The usual AMT test procedure is to set the 11th stage compressor customer bleed at 1.5 lbs/sec and leave it constant throughout the endurance portion of the program. However, since D-Bay cannot supply heated inlet air in this test, customer bleed was used to keep the turbine stator inlet temperature at as high a level as possible during low engine inlet temperature operation. Bleed flow was varied between 1.5 lbm/sec and 4.5 lbm/sec depending on the temperature of the day by changing an oriface plate at the bleed discharge port. Six different bleed settings were possible. A special algorithm was built into the control computer so that a calculated turbine inlet temperature could be displayed and monitored "on line". Based on this reading, the 11th stage bleed was changed to maintain operation at acceptable levels of turbine inlet temperature.

Allison felt that in order to obtain meaningful results from this AMT test, turbine inlet temperature at intermediate power should be greater than 2100°F. The combination of bleed and some engine control adjustments made it possible to run above this lower limit with ambient temperature as low as 30°F. On days colder than this, "B" cycles were run since the engine only reaches idle power and there is little impact of ambient temperature.

RETRIM

With normal TF41 trim, when the engine inlet temperature is less than about 70°F, the engine is governed at intermediate power by the "mass flow limiter" which in effect limits the fan corrected speed to some predetermined value. This causes the lapse in turbine inlet temperature on cold days which adversely impacts the ability to run TF41 AMT tests in the cold weather in D-Bay. The specified mass flow limit on the TF41 is set by the inlet size of the A7. In the test cell, this limit is not applicable and the mass flow limiter can be adjusted to higher levels without damaging the engine. However, the initial retrim resulted in occasional low pressure rotor overspeeds during accels so it was reset. Table 2 contains a summary of the "as received" and retrimmed parameters for operation on the mass flow limiter.

INLET TEMPERATURE/TURBINE STATOR INLET TEMPERATURE (T4) TIME SUMMARY

Previous TF41 AMT tests were run with controlled engine inlet temperature. Forty-one percent of the test was run at 70°F ± 5°F, 38% was run at 90°F ± 5°F, 9% was run at 110°F ± 5°F, and the remaining 12% (the "C" cycles) were run at various inlet temperatures. It was not possible to match this distribution since D-Bay does not have any means for controlling the inlet air temperatures. The ambient temperature distribution that was run during this test is presented in Figure 6.

One of the important parameters in an AMT test is the turbine stator inlet temperature (T4) time history. Enough data is recorded during the six minute intermediate power "flat" near the end of each "A" cycle to allow calculation of a turbine stator inlet temperature (see Appendix A). Figure 6 is a histogram plot of this T4 data for the AMT test of TF41 S/N 142163. Despite the cold ambient temperatures that the test was run

TABLE 2

MASS FLOW LIMITER TRIM

PARAMETER	AS RECEIVED	INITIAL RETRIM	FINAL RETRIM
$NL/\sqrt{\theta 59}$	8780 rpm	9080 rpm	8980
$WA\sqrt{\theta}/\delta$	254 LB_m/sec	265 LB_m/sec	261 LB_m/sec

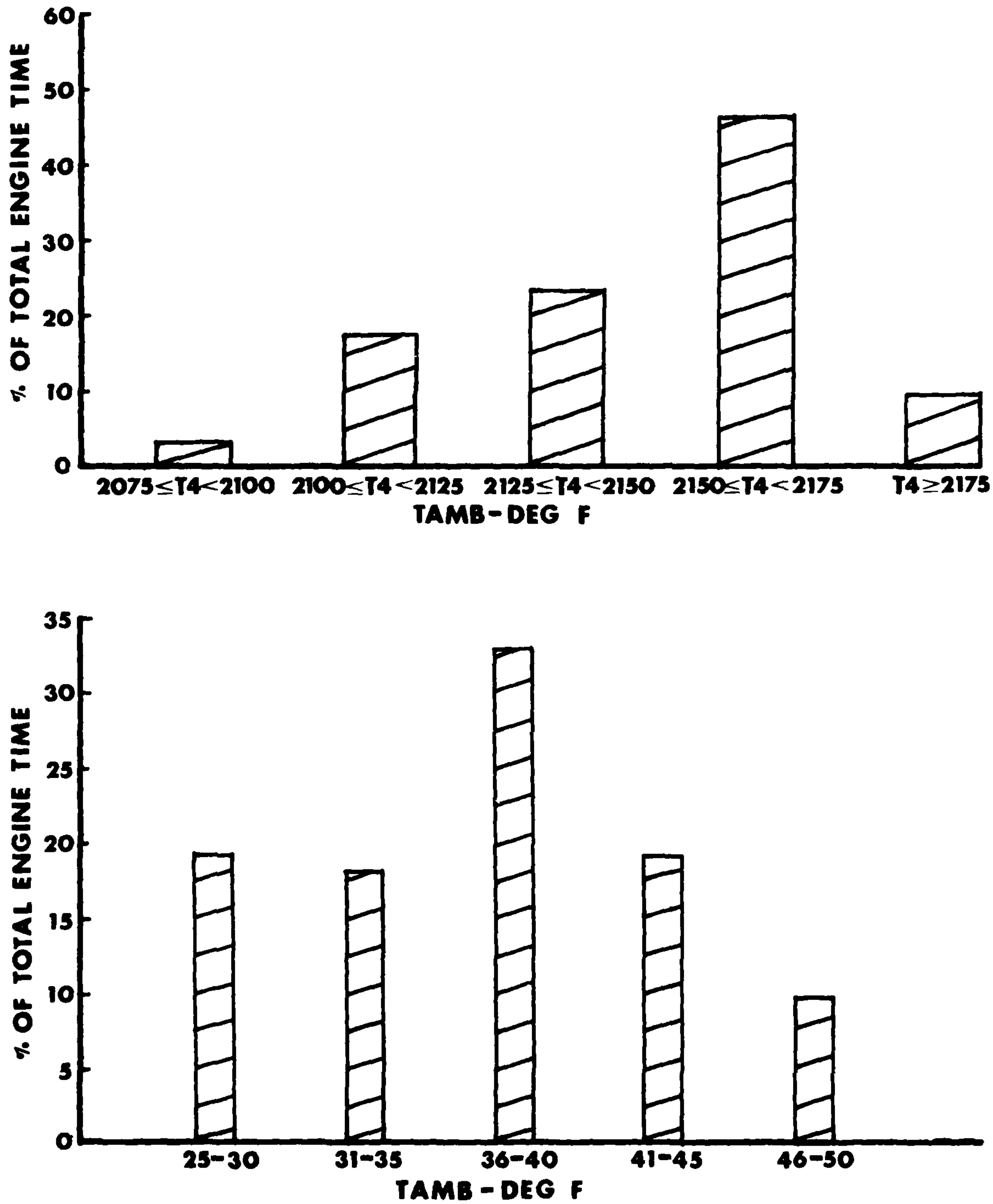


FIGURE 6 - AMBIENT TEMPERATURE AND CALCULATED TURBINE STATOR INLET TEMPERATURE TIME HISTORY

at, the use of the customer bleed and the retrimmed mass flow limiter resulted in a favorable turbine stator inlet temperature distribution. The maximum calculated turbine inlet temperature observed was 2183°F.

It should be noted that this data only represents the T4 distribution at one steady-state condition. It does not reflect any transient conditions or part power.

FUNCTIONAL CHECK DATA

Functional checks of the engine's limiters, governors, and schedules were performed before the test and after 100 AMT hours. The following checks were made according to T.O. 2J-TF41-6 (Ref 6) procedures: NL governor, P3 limiter, T5.1 pulldown, NH governor, and acceleration control unit (ACU) and deceleration control unit (DCU). IGV ram closing schedule could not be checked due to instrumentation problems. NH governor was checked initially but could not be checked at 130 hours due to interference with some IECMS instrumentation which was installed after the start of the test. The results of these checks are contained in Tables 3 through 6 and Figure 7. Note that several of the parameters were slightly out of limits but adjustments were not made due to a lack of the proper adjustment tools. Discussions with Allison engineers confirmed that these apparent out of limit conditions, even if real, were not important to the overall objectives of this test nor did they present an engine safety hazard.

OIL SAMPLING/CONSUMPTION

MIL-L7808 oil was used during this test. All oil added during the test was recorded. Figures 8 and 9 are plots of oil consumption between fills and overall oil consumption as a function of total engine operating time. Oil consumption was not a problem during this test. The average overall oil consumption decreased from an initial rate of about .2 qts per hour to about .1 qts per hour and remained fairly constant at this level for the remainder of the test.

Oil samples were taken after approximately every 25 engine operating hours and sent to the Air Force Aero Propulsion Laboratory's Fuels and Lubrications Divisions for analysis. The tests performed included foaming,

TABLE 3

NL GOVERNOR CHECK

	T.O. LIMIT	0 HOURS	130 HOURS
NL (rpm)	7947 - 8002	7957	7930*

*Low but no adjustment made

TABLE 4

NH GOVERNOR CHECK

	T.O. LIMIT	0 HOURS	130 HOURS
NH (rpm)	13000-13070	12992*	

*Low but no adjustment made

TABLE 5

P3 LIMITER CHECK

	T.O. LIMIT	0 HOURS	130 HOURS
P3 (PSIG)	145-155	151.3	150.3

TABLE 6

T5.1 PULLDOWN CHECK

	T.O. LIMIT	0 HOURS	130 HOURS
T5.1 (°F)	884.5-888.5	886	886

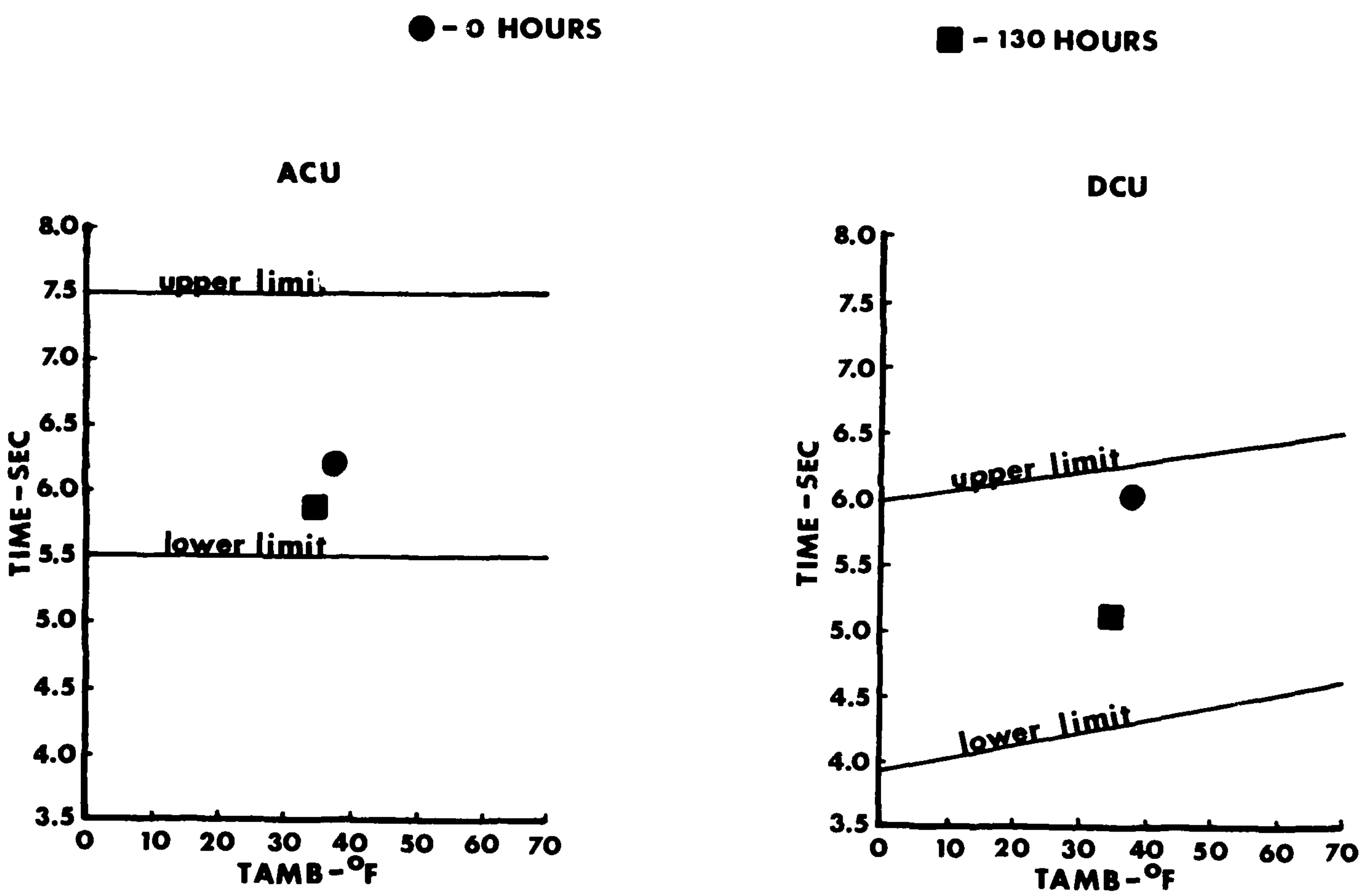


FIGURE 7 - ACU/DCU TIME CHECKS

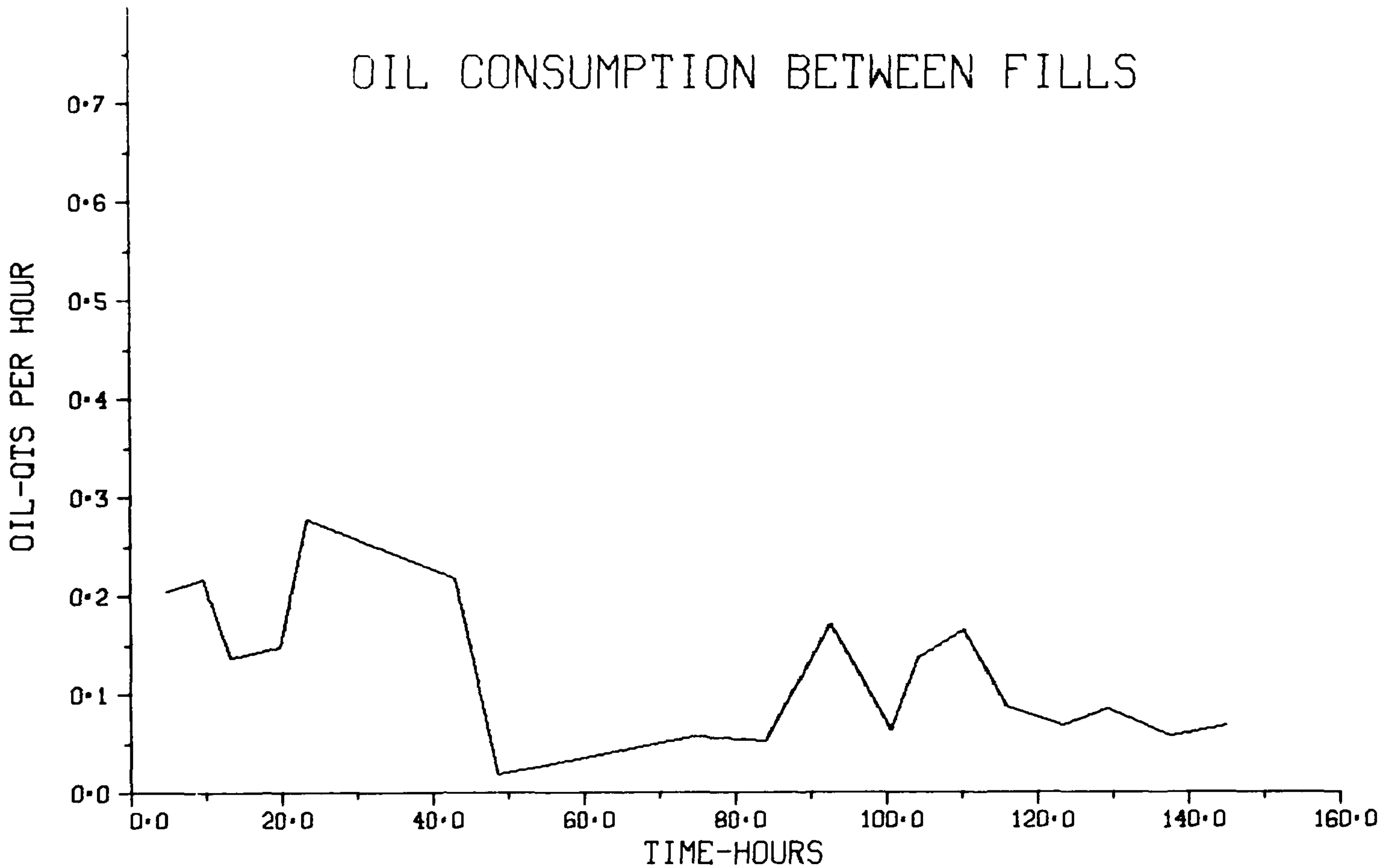


FIGURE 8 - OIL CONSUMPTION BETWEEN FILLS

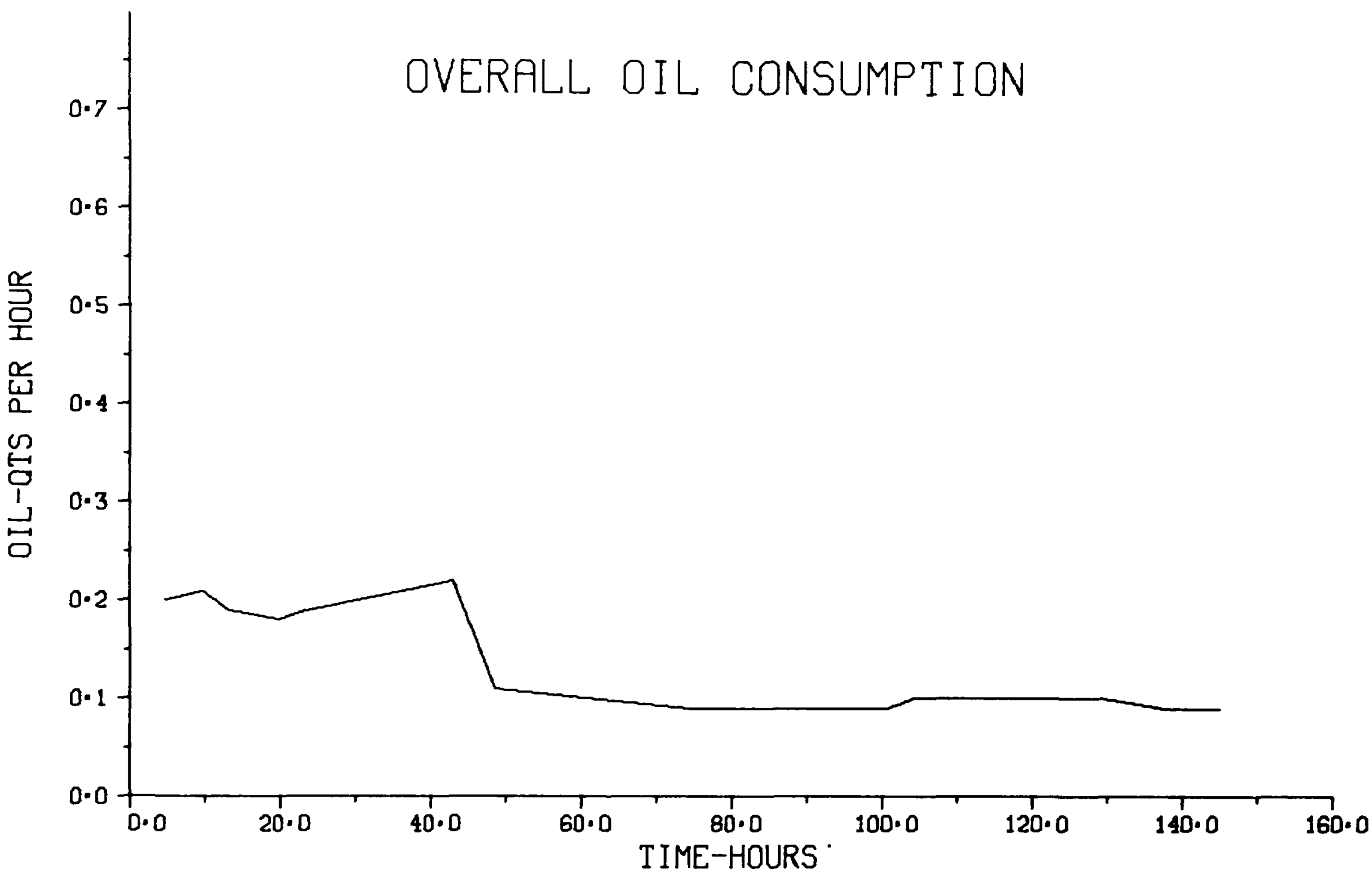


FIGURE 9 - OVERALL OIL CONSUMPTION

spectrometric oil analysis (SOAP), ferrography, viscosity and total acid number determinations. Results of these analyses are contained in Appendix B.

Ferrographic analysis discovered a significant amount of wear debris in the oil after approximately 100 hours of operation. Details of the quantity and types of particles are also contained in Appendix B.

PHASE INSPECTIONS/BORESCOPE

Engine inspections were performed at 50 and 100 AMT hours according to the instructions in Section 7 of Allison publication Nr 1F2, TF4-1A-1 Engine Operation and Service (Ref 7). Eroded ignitor plugs were discovered during these inspections but were the only discrepancies identified.

At approximately 100 AMT hours, the engine was borescoped. It was prepared for borescoping by AFAPL personnel. All fuel nozzles, HPT-2 borescope port plug and intermediate case plugs were removed. The borescope inspection was performed by AFAPL personnel. No apparent problems were found and the results are summarized in Appendix B. After the high turbine vibration caused emergency shutdown during the 183rd "A" cycle the engine was again borescoped by laboratory personnel. No unusual gas path damage was noticed and the results are also summarized in Appendix B.

STARTS AND SHUTDOWNS

The engine in this program did not exhibit any starting difficulties. Two hundred and ten successful engine starts were accomplished. The average peak turbine outlet temperature during these starts was 678°F. The maximum observed peak turbine outlet temperature during a start was 769°F.

HP and LP rotor coastdowns were recorded after the final shutdown of each test period. The coastdown times did not exhibit any significant change throughout the duration of the test and remained well above the T.O. minimums of 60 sec for the LP and 20 sec for the HP.

Initial Coastdowns	LP - 140 sec
	HP - 96 sec
Final Coastdowns	LP - 137 sec
	HP - 98 sec

VIBRATIONS

Turbine, compressor, and mid-frame vibrations were recorded during the power calibrations at 0 and 130 operating hours. In addition, a steady-state power excursion was run following the borescoping and engine inspection after the high turbine vibration caused emergency shutdown when no gas path damage was observed. The vibration data for these three runs are plotted as a function of high pressure compressor rotational speed (NH) in Figure 10. For the first 130+ hours the vibrations remained well below the T.O. limit of 5.0 mils and did not show any significant change with engine operating time. However, following this first stage low pressure compressor stop plate failure, all three vibrations exhibited a definite upward shift in level with the turbine exceeding 5 mils near maximum power.

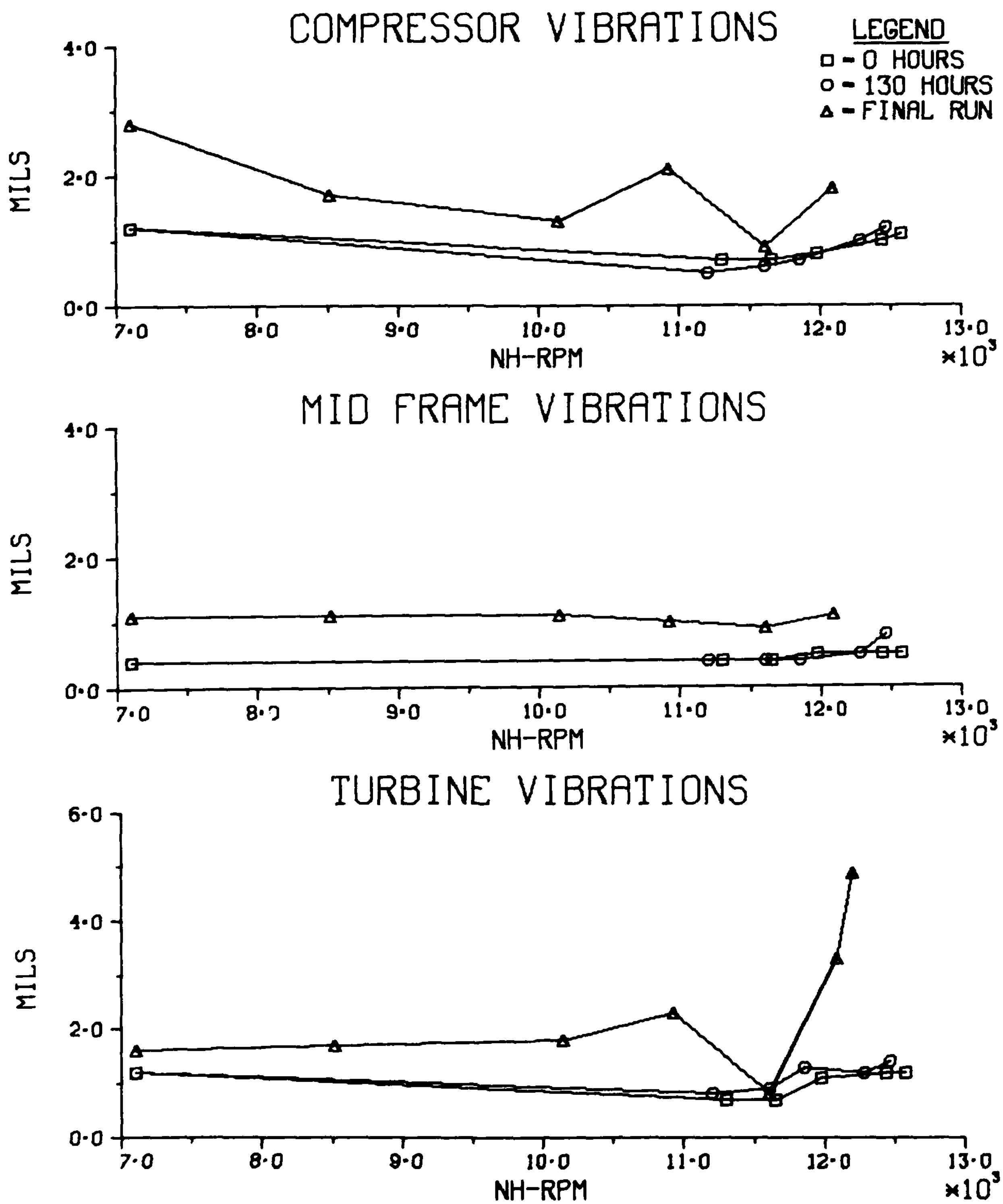


FIGURE 10 - ENGINE VIBRATION HISTORY

SECTION VIII
ENGINE PERFORMANCE

"A" CYCLE PERFORMANCE DATA

A steady-state data point was recorded at intermediate power during the six minute "flat" near the end of each "A" cycle. The raw data was processed through a data reduction computer program based on the equations in Appendix A. Plots of corrected high pressure rotor speed (NHC1), corrected low pressure rotor speed (NLC1), corrected fuel flow (WFC59), corrected turbine discharge pressure (P51C), corrected airflow (W2C1), turbine inlet temperature corrected to 77°F (T4C77), and trimmed turbine exhaust gas temperature corrected to 77°F (T51TC7) and corrected to 59°F (T51TC5) versus thrust corrected to 59°F (FGC59) are presented in Figures 11 through 13.

Even though all the data points plotted are at intermediate power, there is a variation in corrected thrust due to the varying engine inlet temperature varying customer bleed flow and engine deterioration. The relatively large amount of scatter in the data is the result of several factors. The control computer, which acquires the instrumentation signal, processes it, displays it on the CRT, and records it on the line printer, introduces a certain amount of random scatter due to the limited word storage size which limits the number of significant figures available. This problem appears to be most pronounced with thermocouple readings where a ± 6°F "bounce" is introduced and the measured thrust which can only be read to ± 100 lbs. An obvious solution to this problem would be to take many readings over a given time span and average them. However, this is not feasible since data can only be recorded at a once per minute rate and the engine takes nearly five of the six available minutes to stabilize. Even with the scatter, the trends shown by these plots are typical of a TF41, and confirm that the engine was operating properly throughout the test until failure.

MAXIMUM POWER PERFORMANCE DETERIORATION

One of the primary objectives of this test was to quantify engine performance deterioration under realistic usage conditions. In past

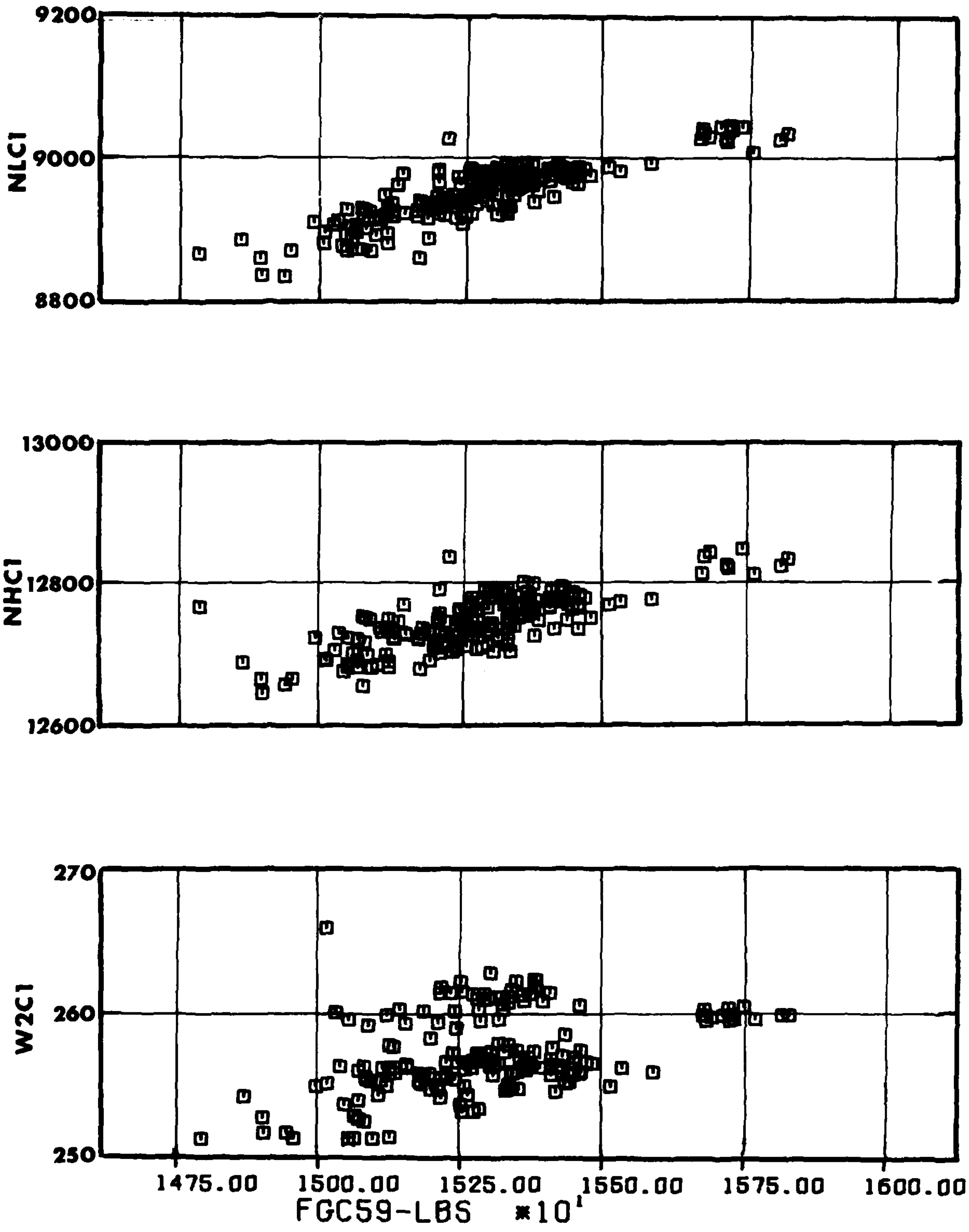


FIGURE 11 - CORRECTED "A" CYCLE PERFORMANCE TRENDS

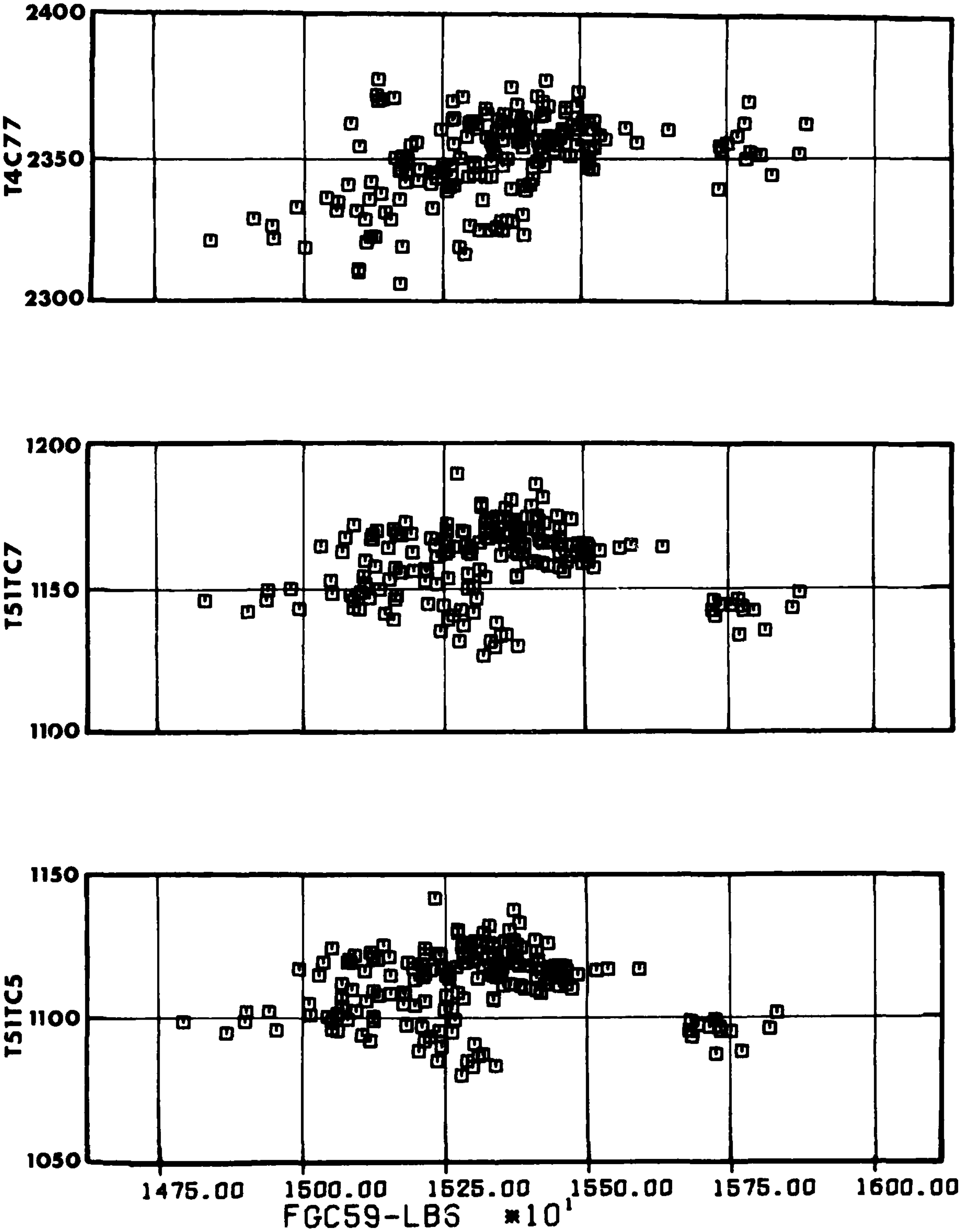


FIGURE 12 - CORRECTED "A" CYCLE PERFORMANCE TRENDS

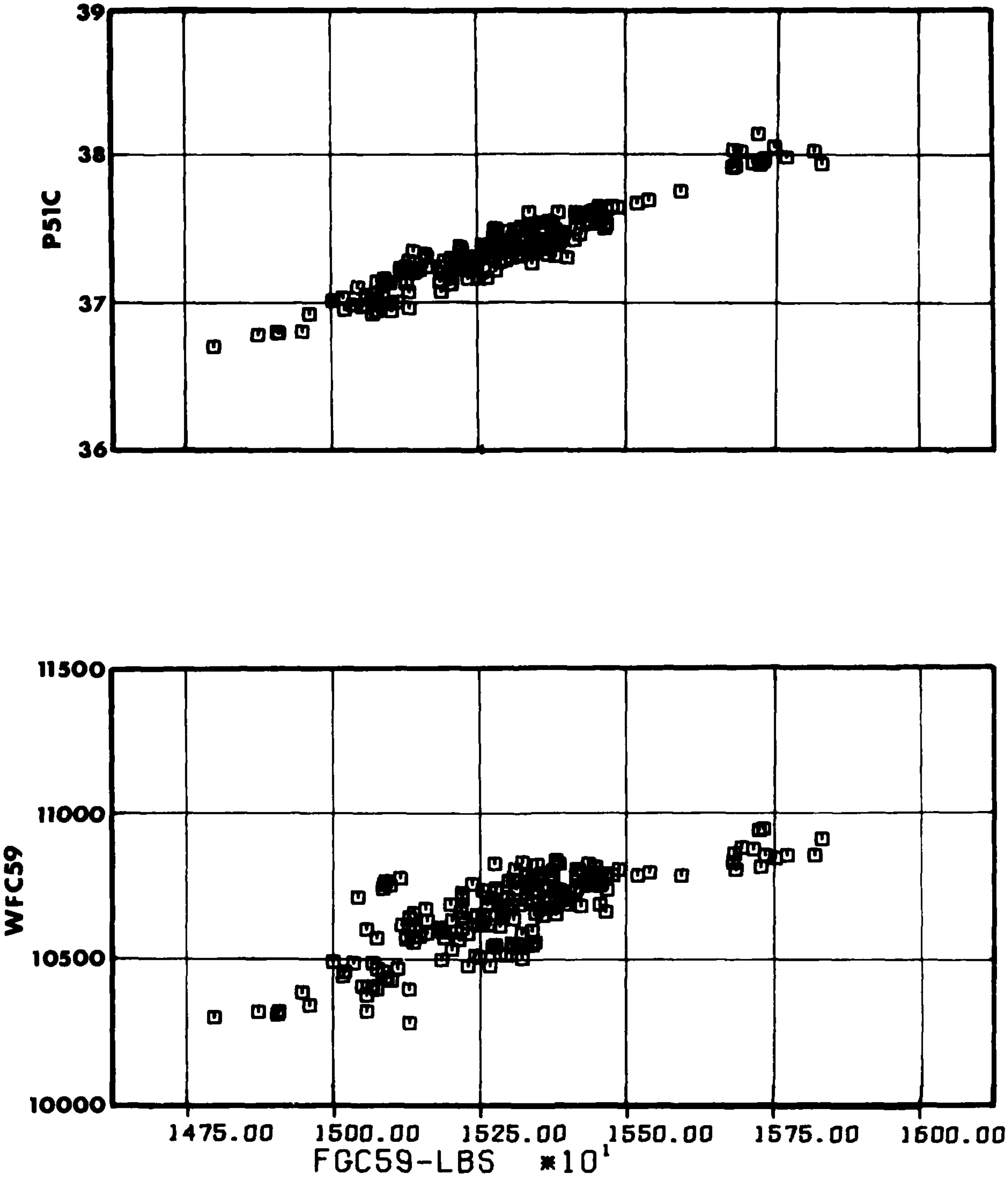


FIGURE 13 - CORRECTED "A" CYCLE PERFORMANCE TRENDS

tests, one approach has been to track maximum power thrust (recorded during the six minute "flat" of each A cycle) as a function of engine operating time. One of the problems with this approach is that thrust is a function of ambient temperature and in Propulsion Laboratory Facilities there is no control over inlet air temperature. Therefore, a search of the data must be made to determine an ambient condition with a reasonable spread in engine hours and enough data points to be able to draw meaningful conclusions. Because of the very limited number of test hours (133) there was a minimal amount of data available for this analysis. With this particular test, the problem was further compounded by the misset mass flow limiter which was adjusted part way into the test (10 AMT hours). This would impact the maximum level of thrust achievable during operation on the mass flow limiter. The varying 11th stage customer bleed also affected thrust. A search of the data from the 183 "A" cycles did not identify any ambient condition with a reasonable spread in operating time, with the same customer bleed flow rate, and the same mass flow limiter setting.

Another method for tracking engine performance deterioration makes use of the entire mass of the "A" cycle data despite the difference in inlet temperature. This approach assumes that all corrected engine parameters are linear functions of corrected thrust and the slopes of these functions do not change with deterioration. Thus all the data could be extrapolated to the same condition allowing a consistent comparison as a function of total engine operating time. (See Ref 2). However, the varying customer bleed invalidated the constant slope assumption so this technique could not be used.

Therefore, no conclusions could be drawn from the "A" cycle data as to the impact of engine deterioration on maximum power performance. However, the part power performance calibration data can be used to infer some of the deterioration effects.

PERFORMANCE CALIBRATIONS

Steady-state power calibrations were performed before the AMT test and after 100 AMT hours (130 total test hours). The engine was allowed to stabilize for at least five minutes before data was recorded at four

or five power settings between 8500 pounds thrust and intermediate power. Two complete data points were recorded after the engine had stabilized and were averaged. The data was then corrected according to the procedures outlined in Appendix A.

Fan and intermediate pressure compressor discharge temperature and pressure probes were used during the steady-state power calibration portion of the test. Normal test procedures call for this instrumentation to be inserted in the forward borescope ports on either side of the engine. However, the design of the thrust frame adapter did not allow access to the left hand port. Thus, two separate calibrations had to be run, one with pressure and one with temperature instrumentation. The data was then plotted as a function of corrected low pressure compressor rotor speed in order to establish a consistent set of pressures and temperatures.

Figures 14 through 17 compare the AFAPL pre-test performance calibrations with Allison's "as shipped" performance data (Ref 8). The overall engine performance data (Figures 14 and 15) show excellent agreement with the Allison data. However, the AFAPL compression system component data in some cases (Figures 16 and 17) show a 1%-2% difference with the "as shipped" data. This is probably largely due to the inability to run both compressor pressure and temperature instrumentation simultaneously. This does not present a major problem though, since the changes in these parameters are more important than their absolute values.

Figures 18 through 33 present plots of the corrected performance data for the two steady-state power calibrations. The difference in maximum thrust level between the two runs is due to different mass flow limiter settings. In general, the observed changes in performance are in the same direction but of a smaller magnitude than seen in earlier tests (Ref 1, 2, 3). The most significant changes appear to be a 0-10°F increase in turbine inlet temperature, a 10°F increase in exhaust gas temperature and 0-1% increase in specific fuel consumption at constant thrust.

The addition of the inter-compressor instrumentation allows calculation of the individual compressor component efficiencies. This data is presented in Figure 34. This data does not show any significant deterioration in compression system component performance and is consistent with the minimum overall engine deterioration effects seen in the earlier plots.

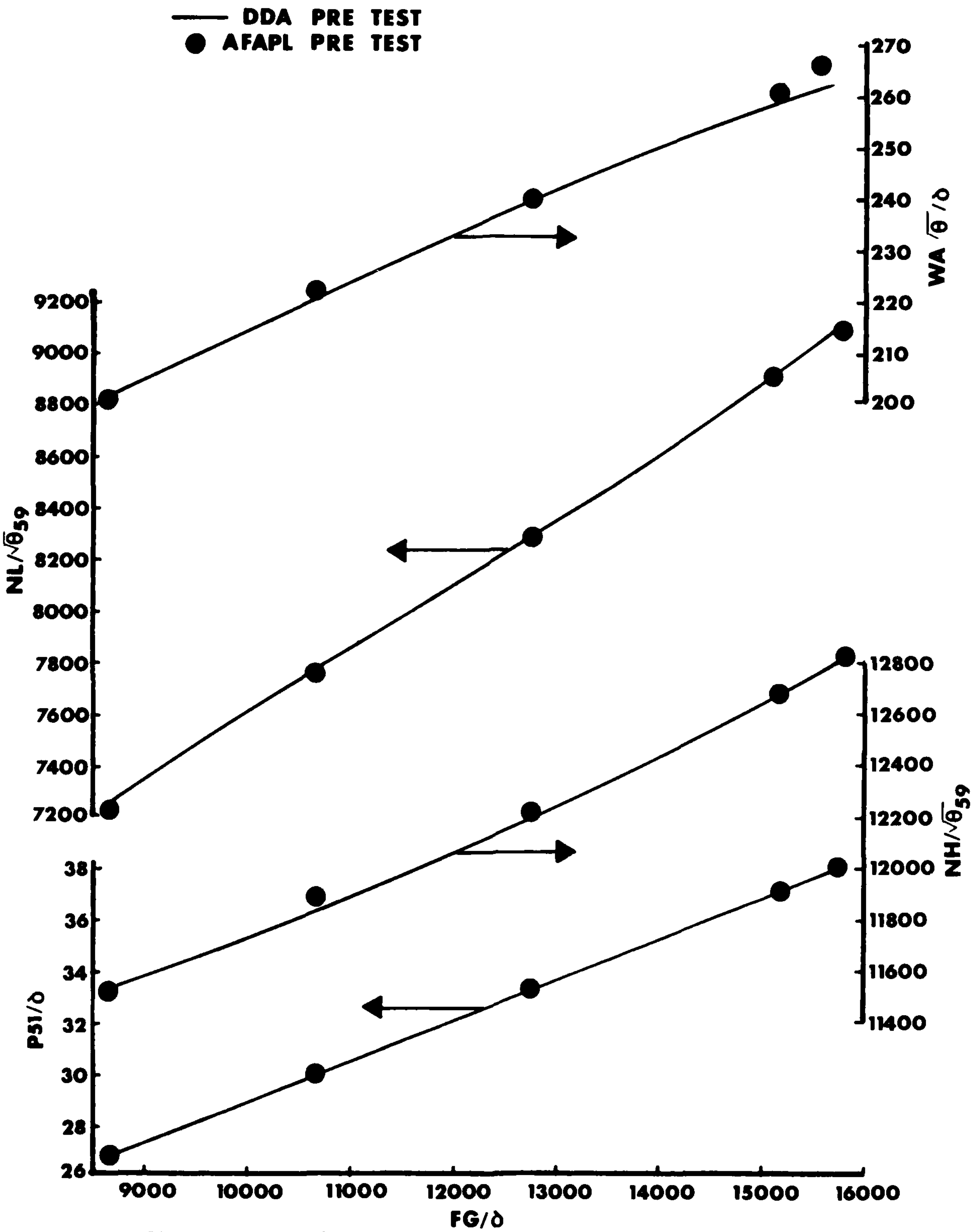


FIGURE 14 - COMPARISON OF AFAPL AND DDA PRE-TEST POWER CALIBRATION DATA

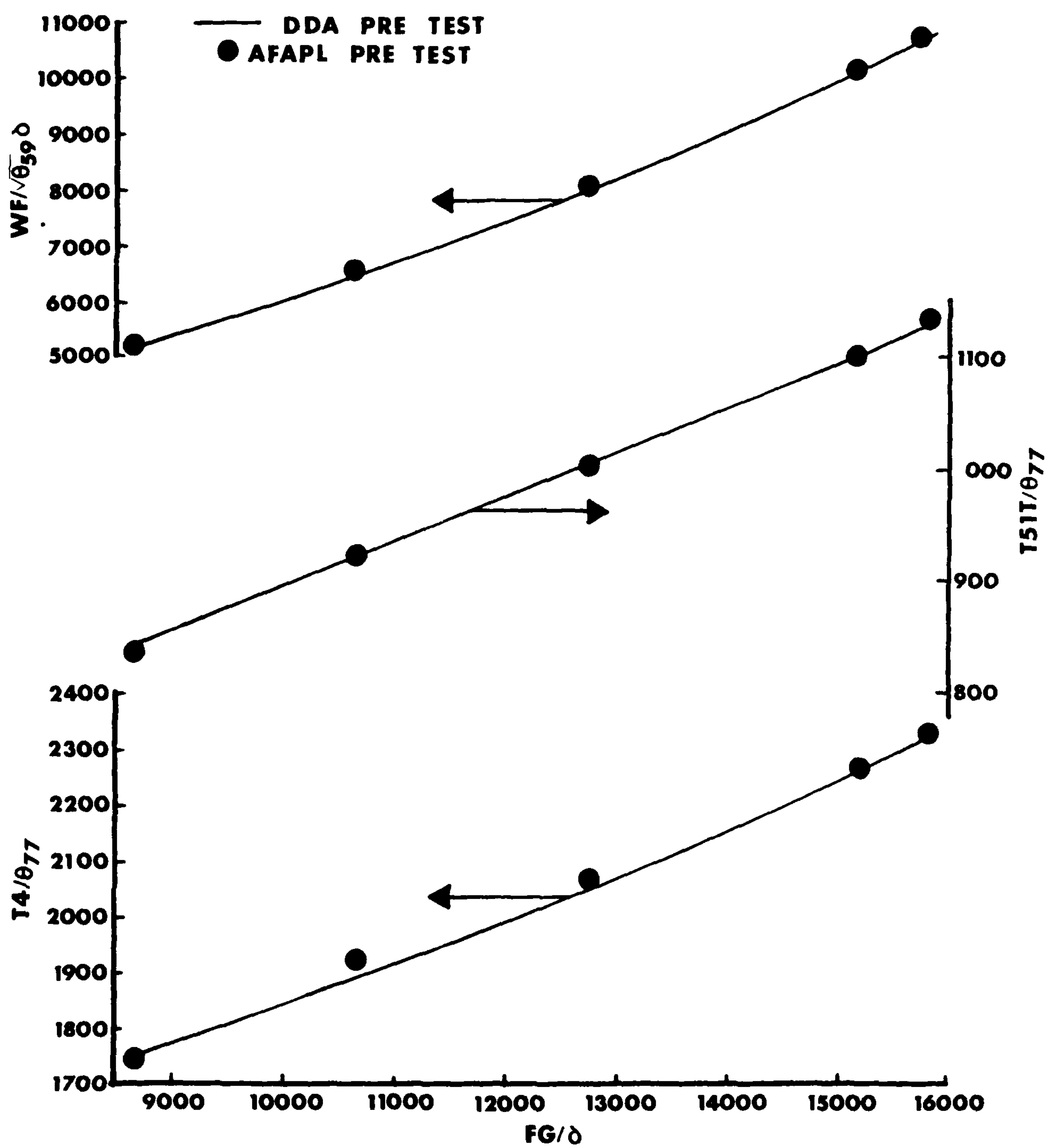


FIGURE 15 - COMPARISON OF AFAPL and DDA PRE-TEST POWER CALIBRATION DATA

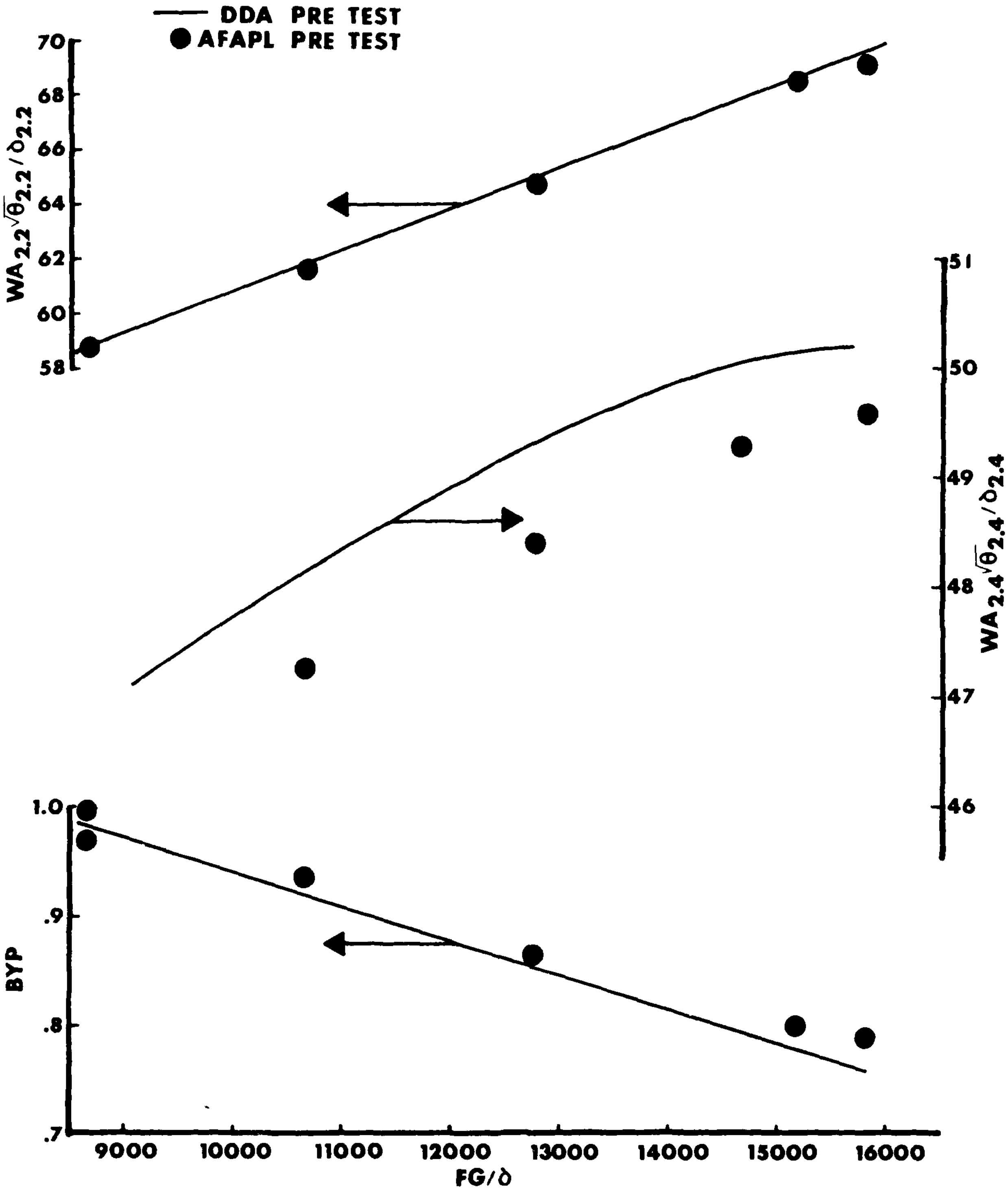


FIGURE 16 - COMPARISON OF AFAPL AND DDA PRE-TEST POWER CALIBRATION DATA

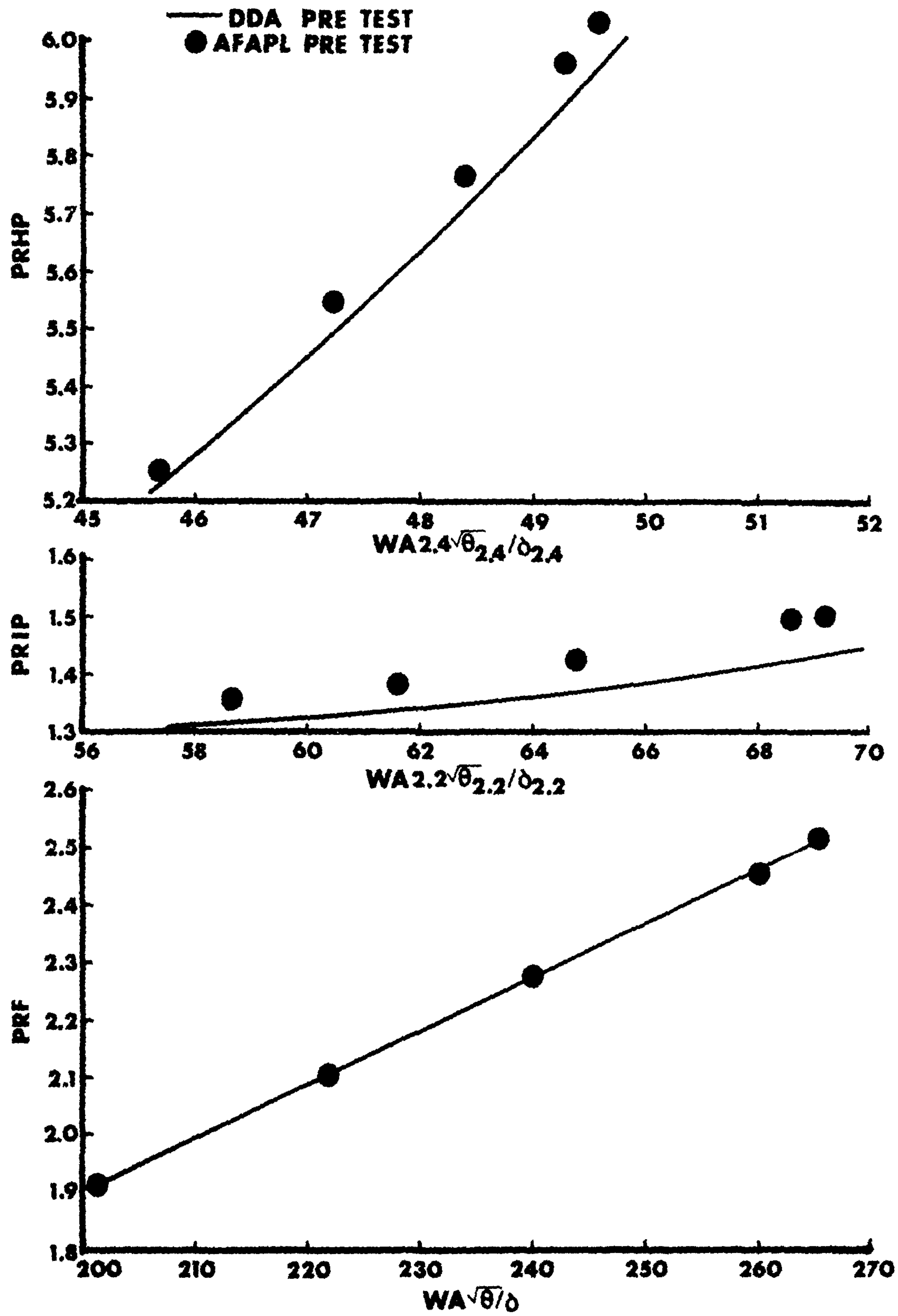


FIGURE 17 - COMPARISON OF AFAPL AND DDA PRE-TEST POWER CALIBRATION DATA

CORRECTED L. P. ROTOR SPEED VS CORRECTED THRUST

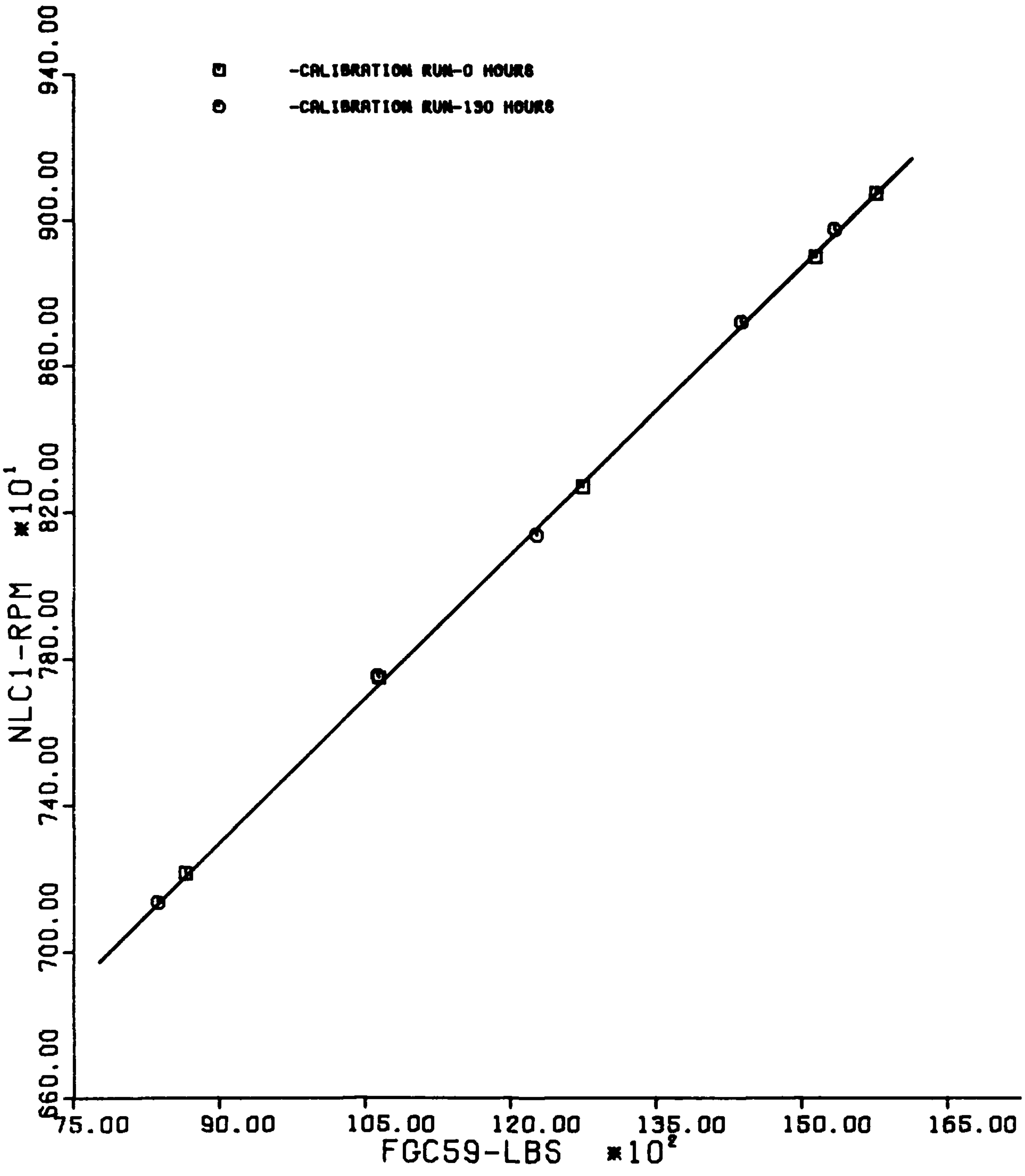


FIGURE 18 - CORRECTED L.P. ROTOR SPEED VERSUS CORRECTED THRUST

CORRECTED EXHAUST GAS PRESSURE VS CORRECTED THRUST

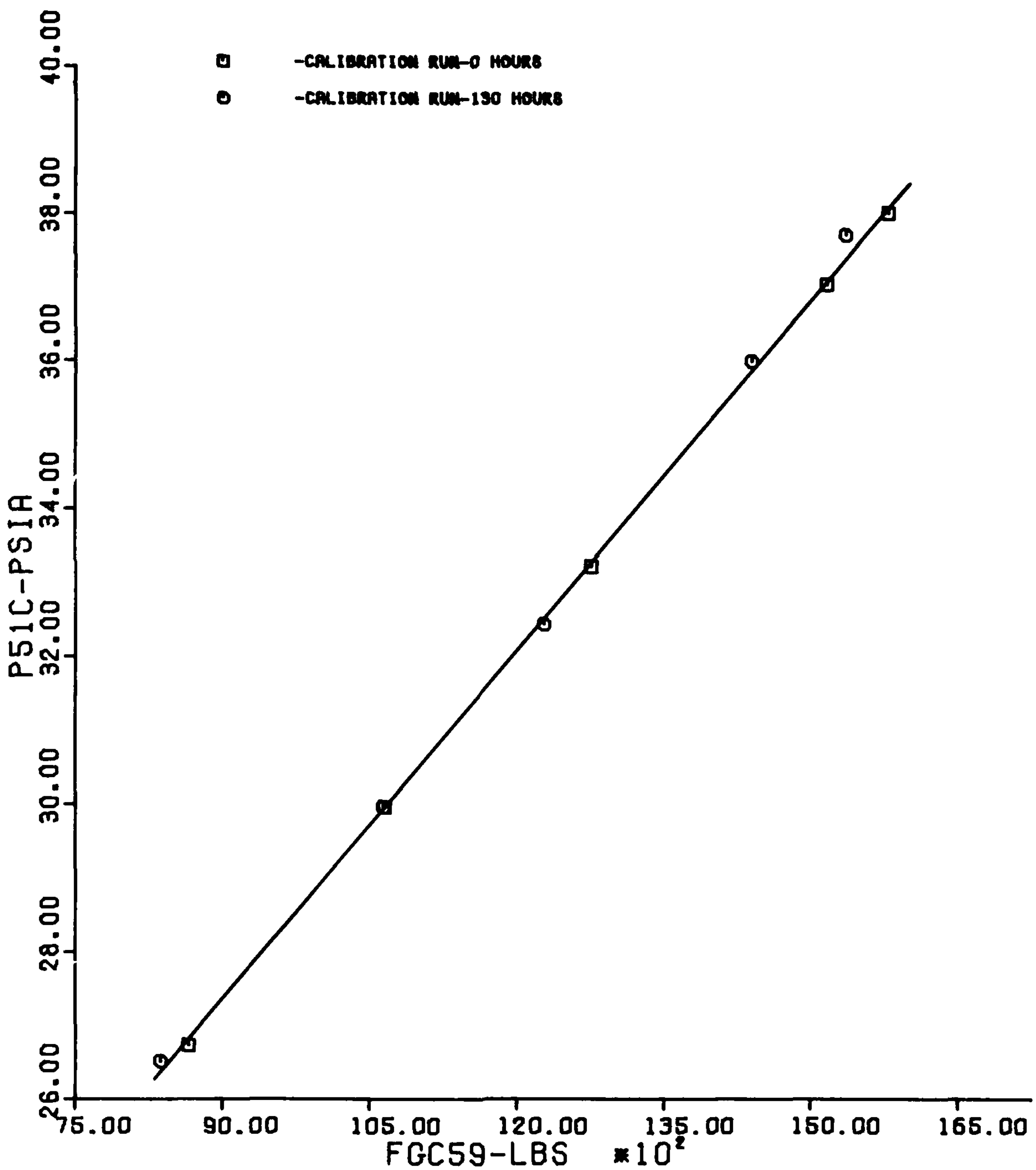


FIGURE 19 - CORRECTED EXHAUST GAS PRESSURE VERSUS CORRECTED THRUST

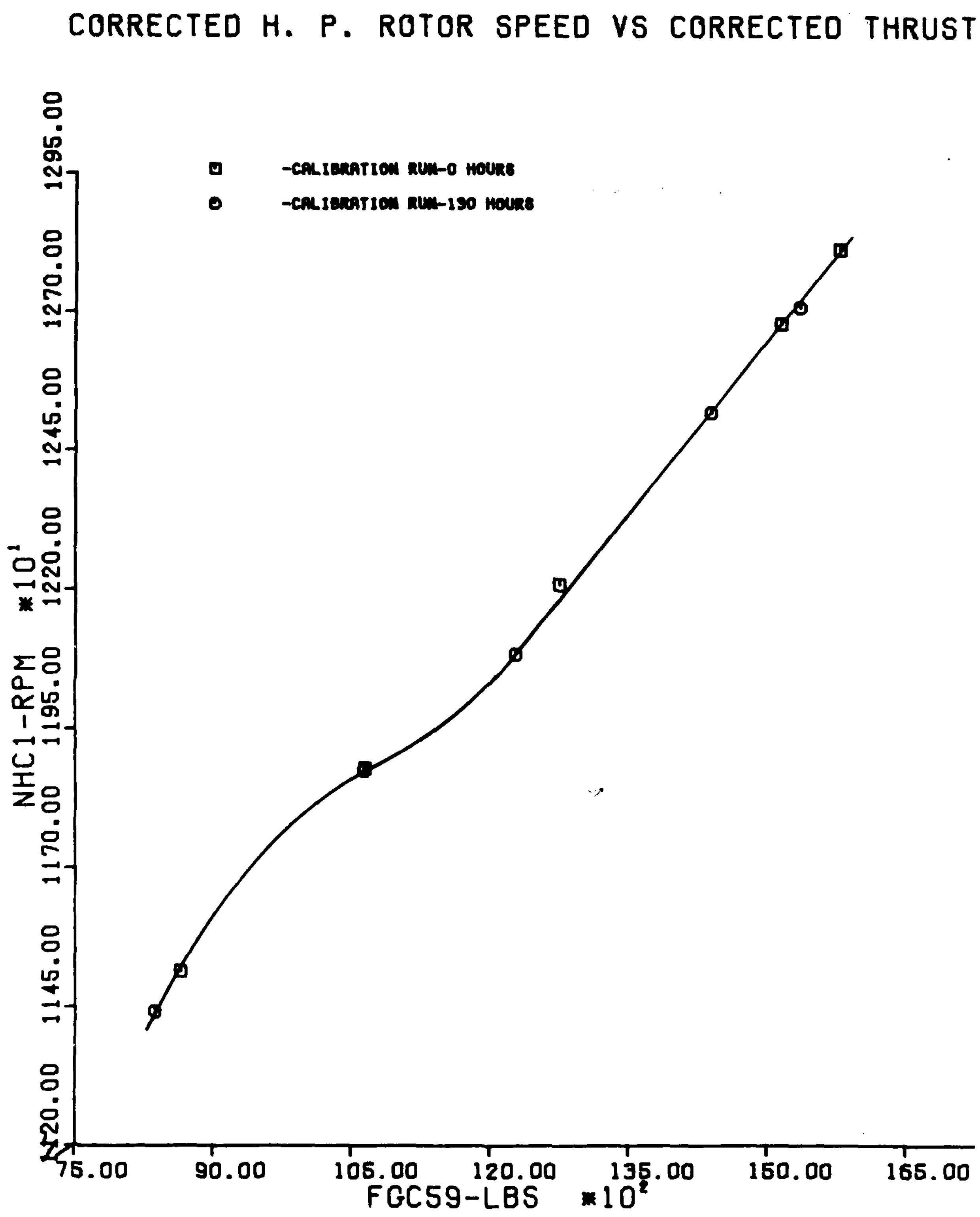


FIGURE 20 - CORRECTED H.P. ROTOR SPEED VERSUS CORRECTED THRUST

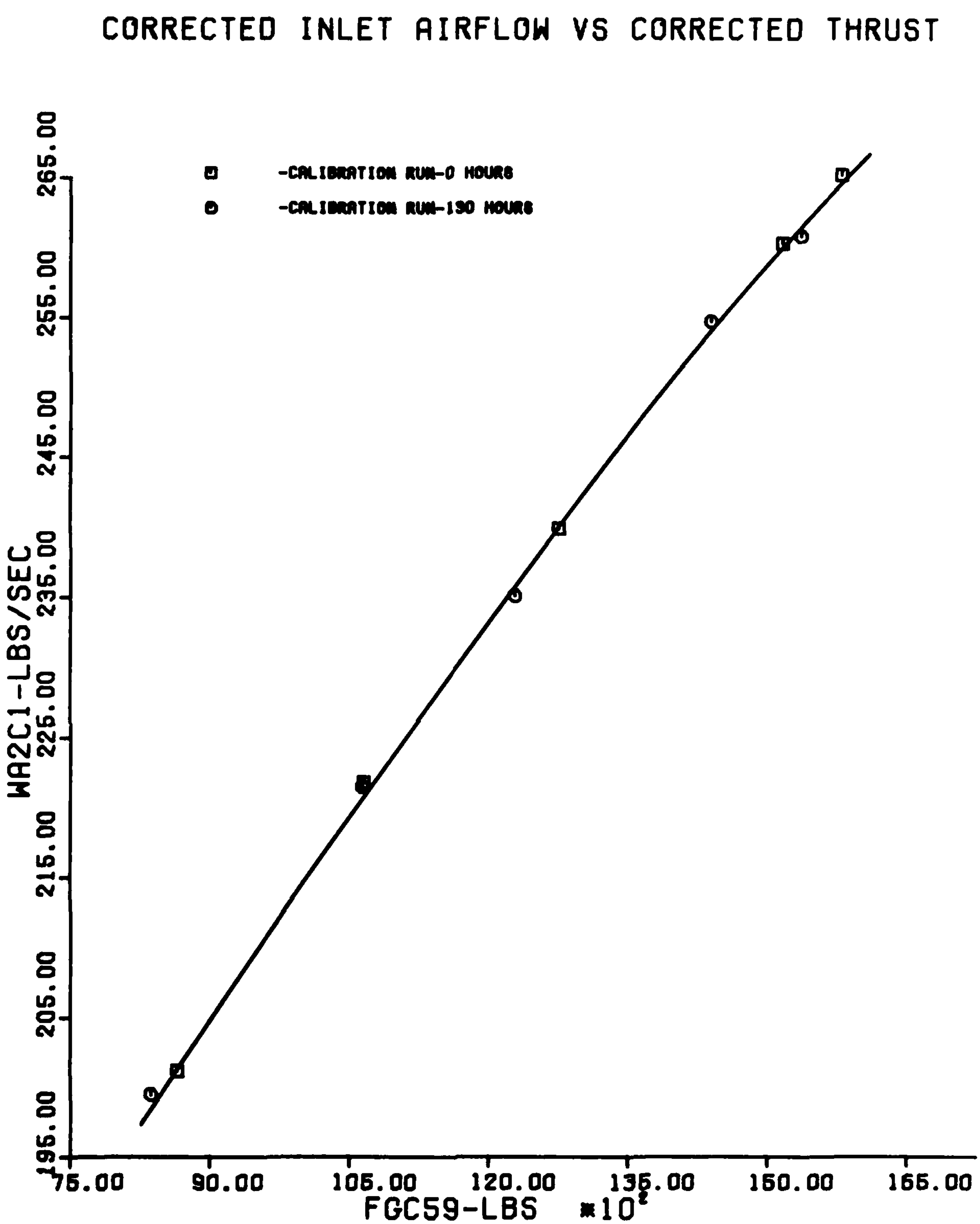


FIGURE 21 - CORRECTED INLET AIRFLOW VERSUS CORRECTED THRUST

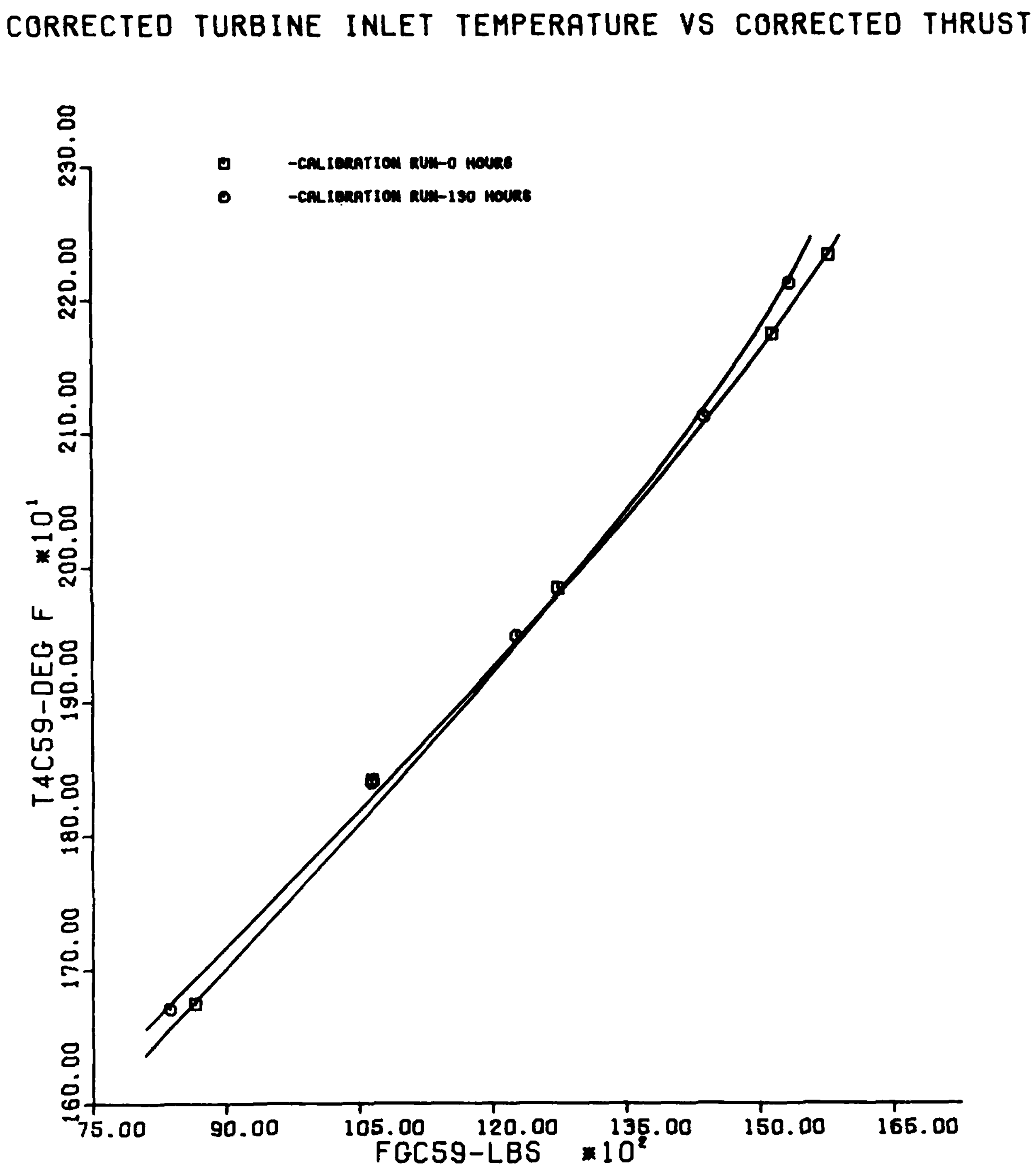


FIGURE 22 - CORRECTED TURBINE STATOR INLET TEMPERATURE VERSUS CORRECTED THRUST

CORRECTED TURBINE INLET TEMPERATURE VS CORRECTED THRUST

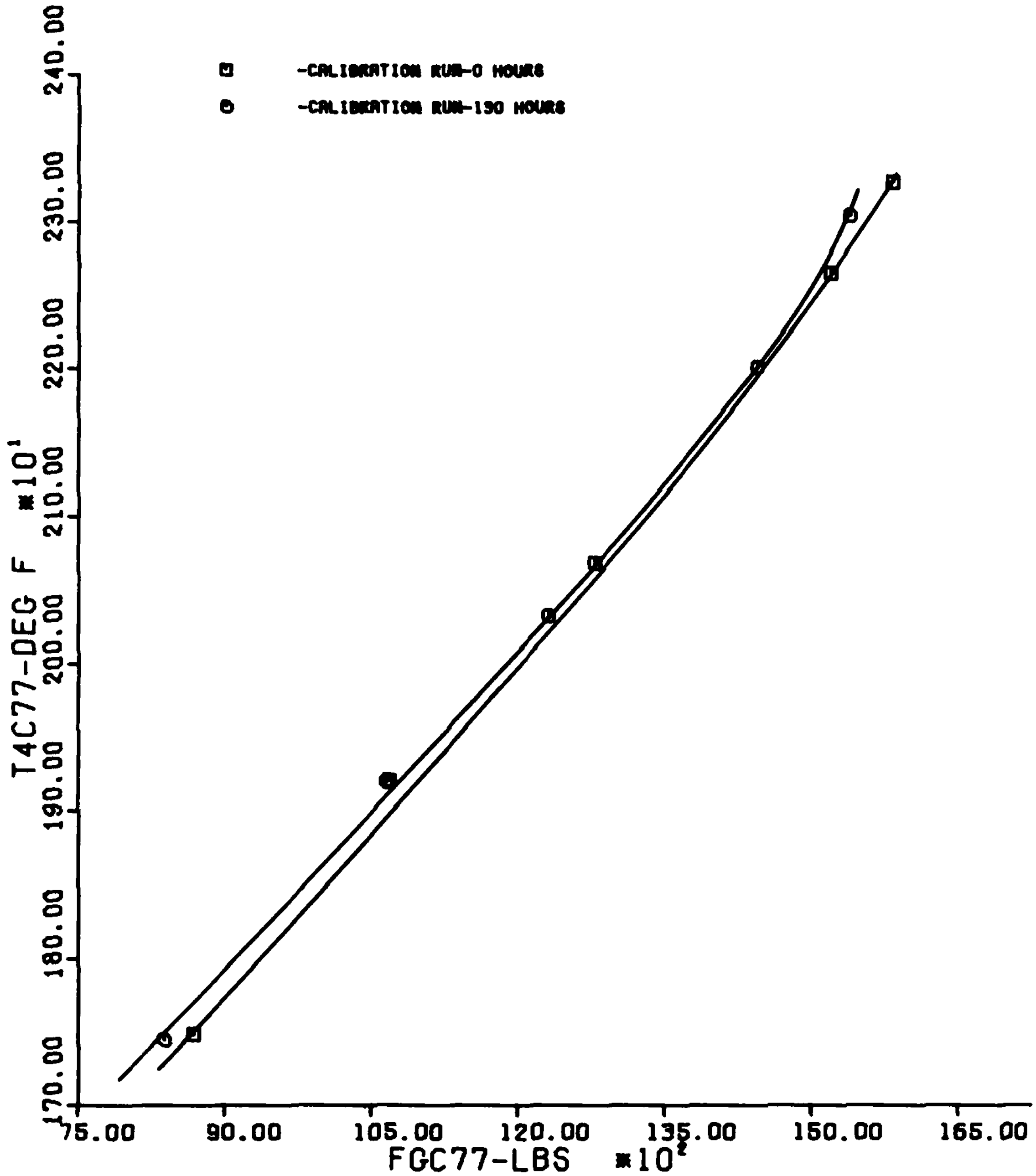


FIGURE 23 - CORRECTED TURBINE STATOR INLET TEMPERATURE VERSUS CORRECTED THRUST

CORRECTED EXHAUST GAS TEMPERATURE VS CORRECTED THRUST

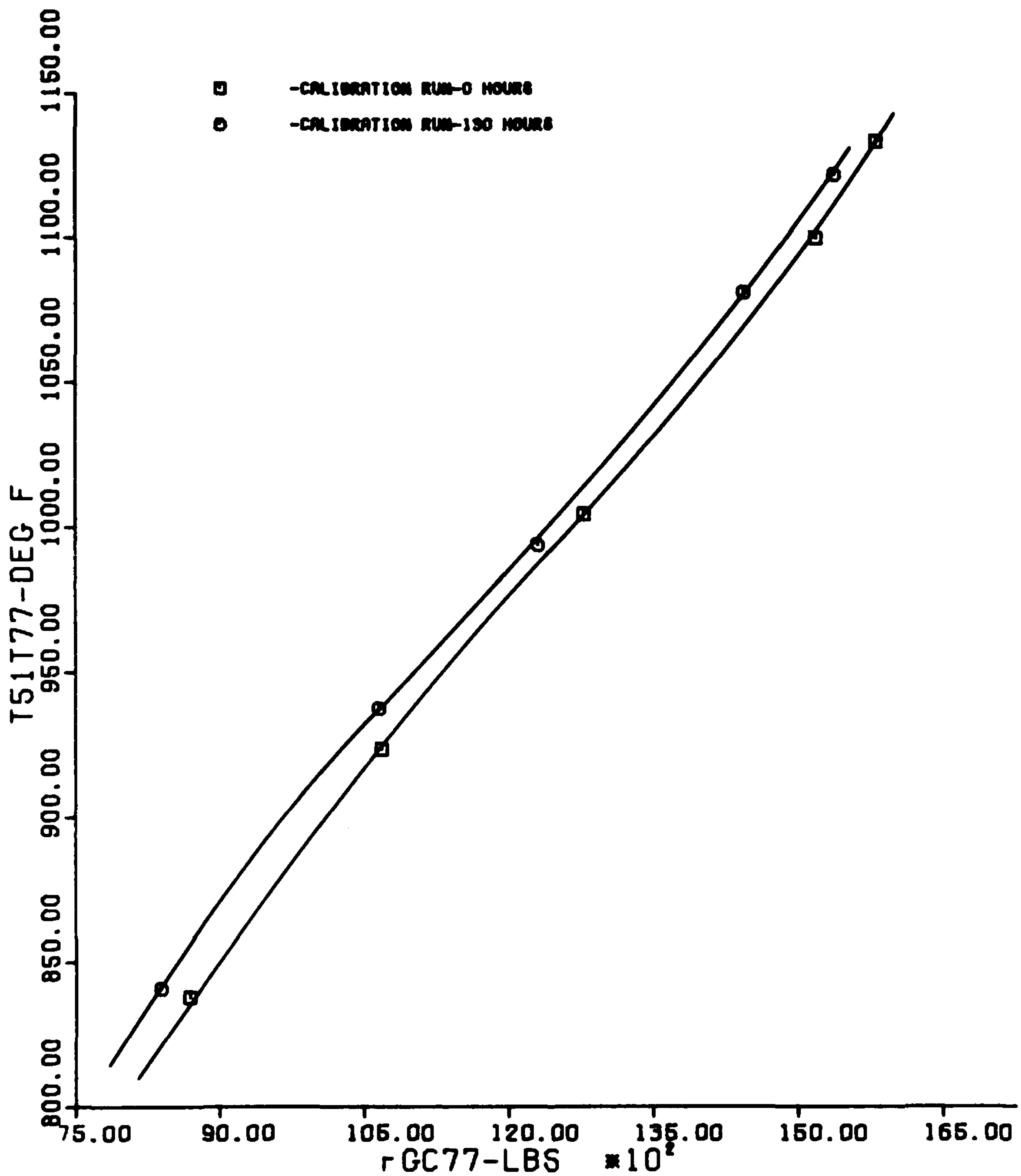


FIGURE 24 - CORRECTED EXHAUST GAS TEMPERATURE VERSUS CORRECTED THRUST

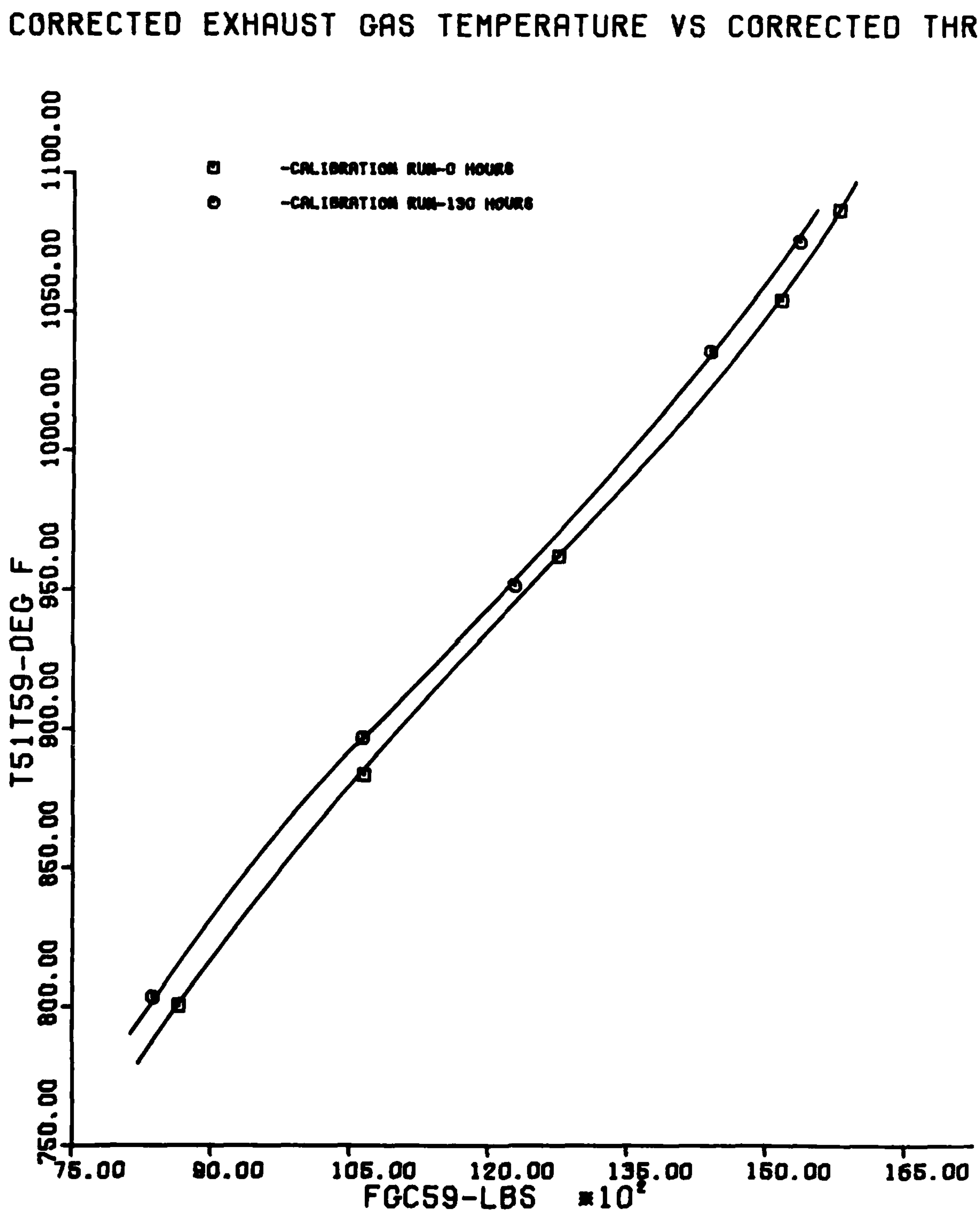


FIGURE 25 - CORRECTED EXHAUST GAS TEMPERATURE VERSUS CORRECTED THRUST

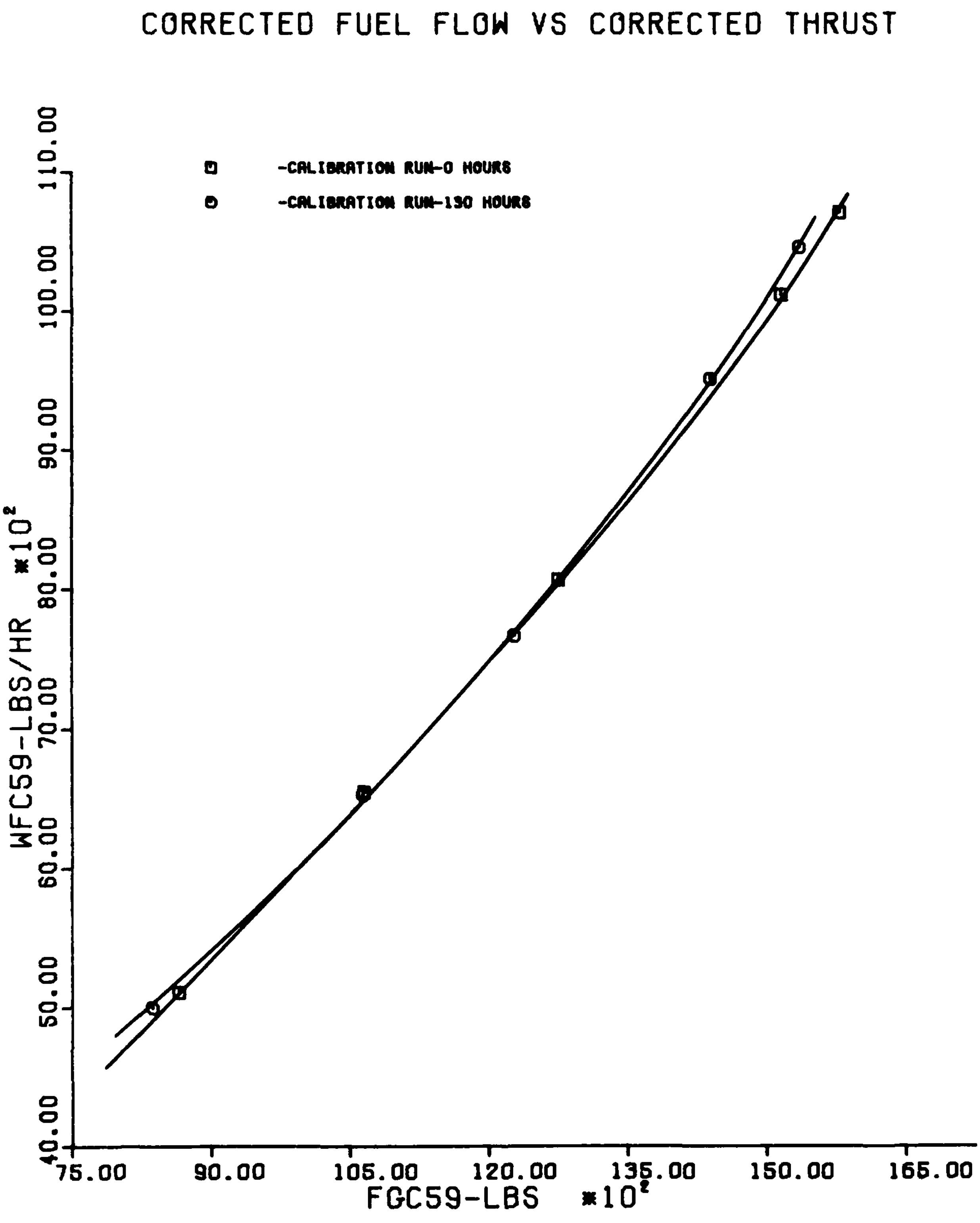


FIGURE 26 - CORRECTED FUEL FLOW VERSUS CORRECTED THRUST

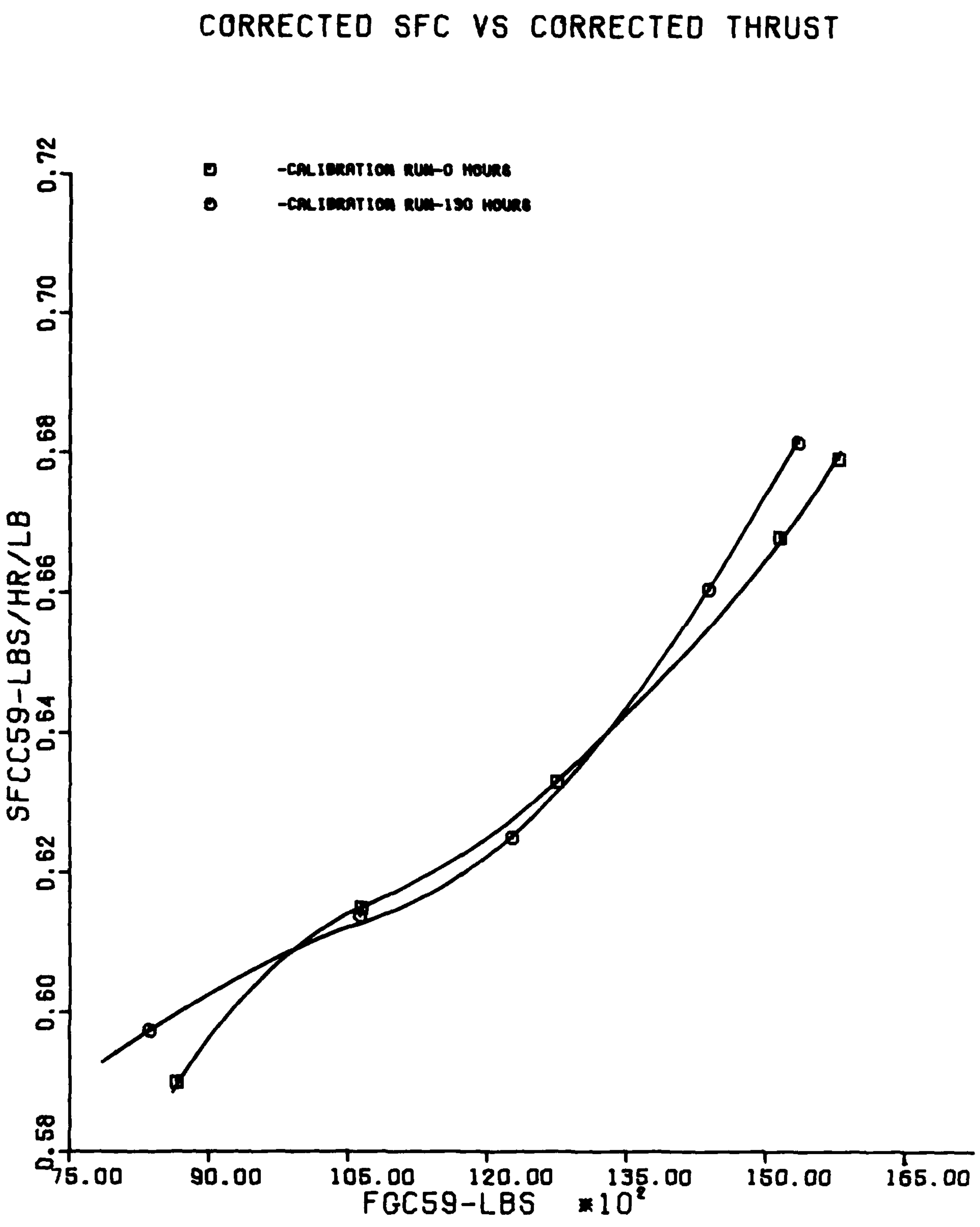


FIGURE 27 - CORRECTED SFC VERSUS CORRECTED THRUST

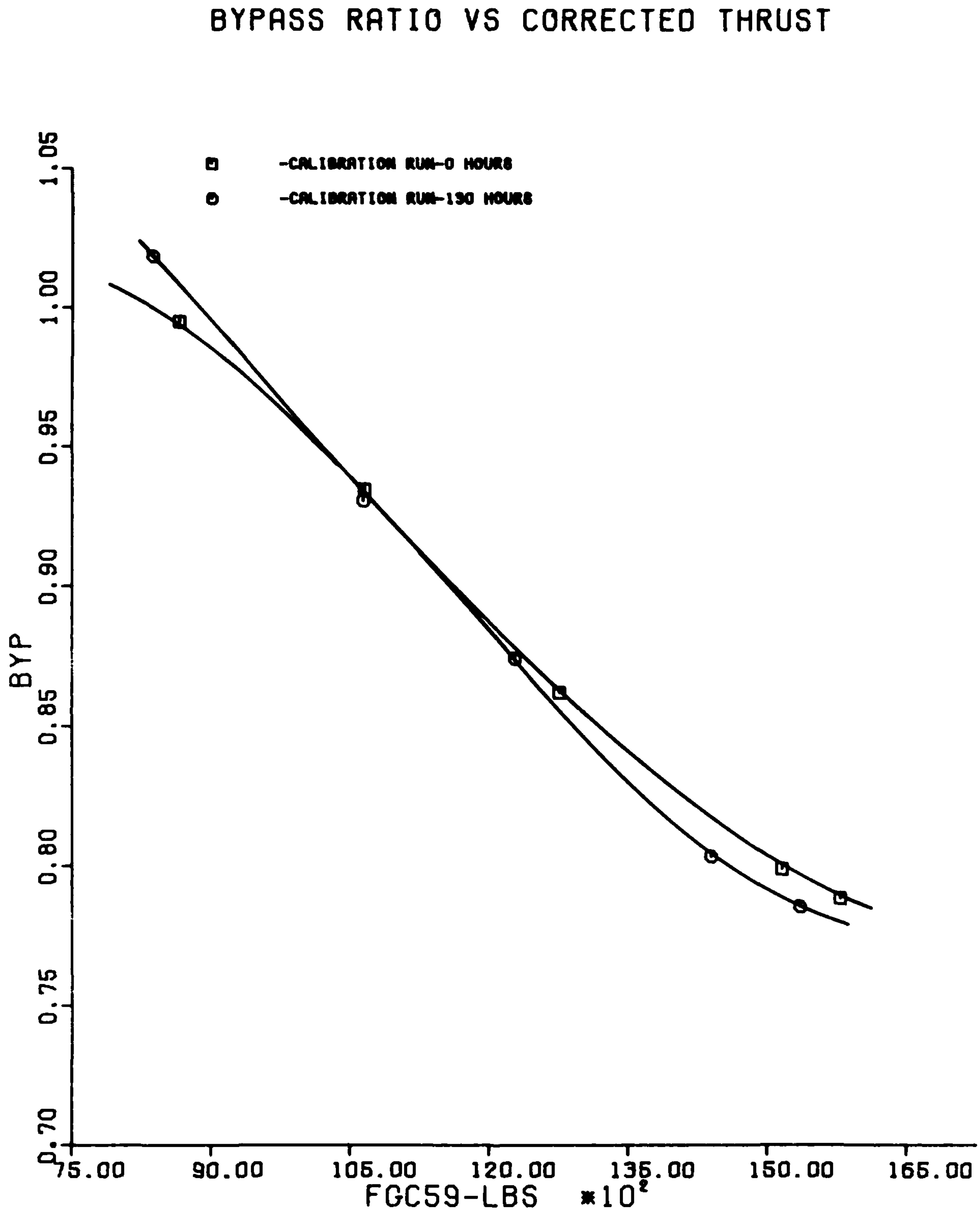


FIGURE 28 - BYPASS RATIO VERSUS CORRECTED THRUST

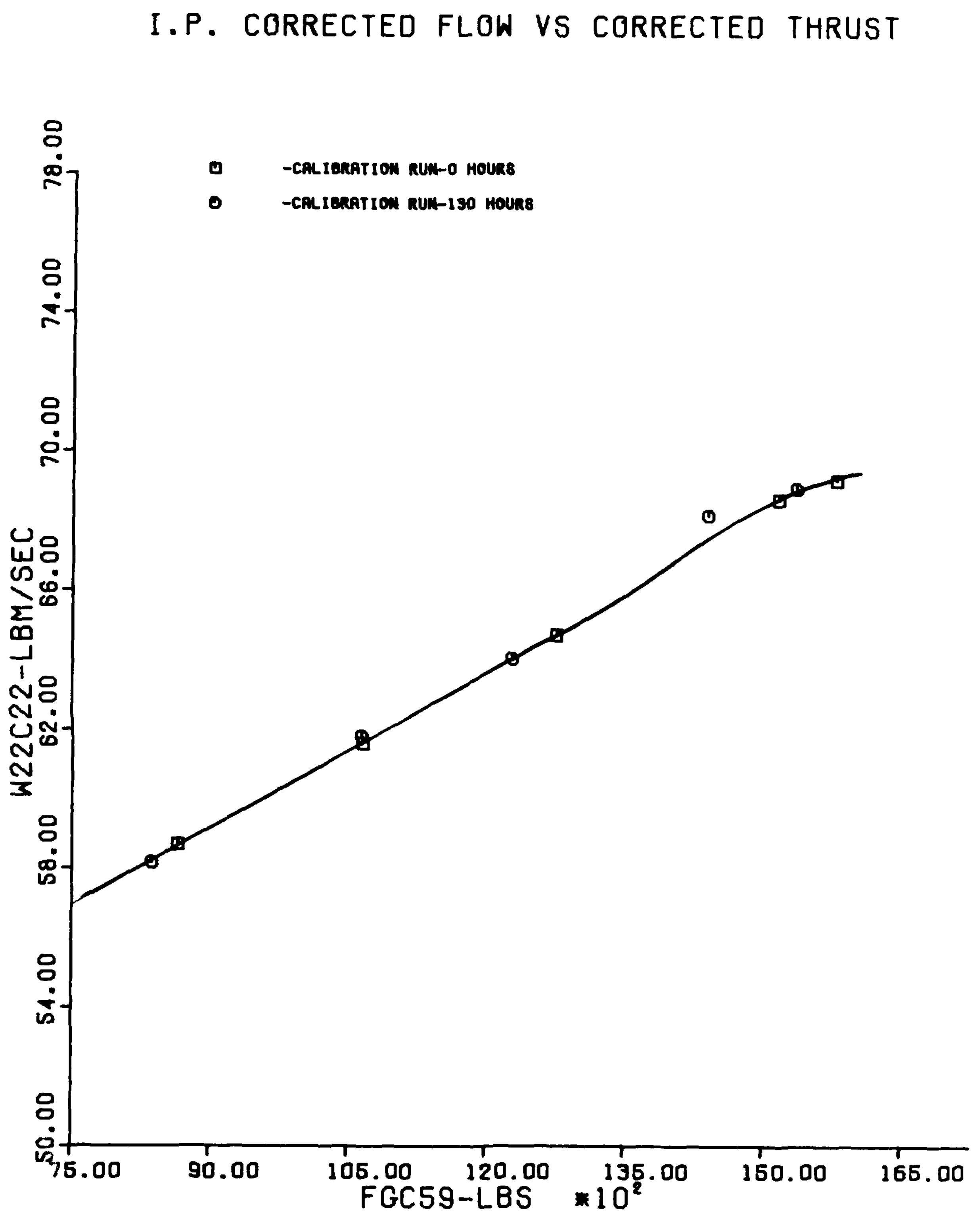


FIGURE 29 - I.P. CORRECTED FLOW VERSUS CORRECTED THRUST

H.P. CORRECTED FLOW VS CORRECTED THRUST

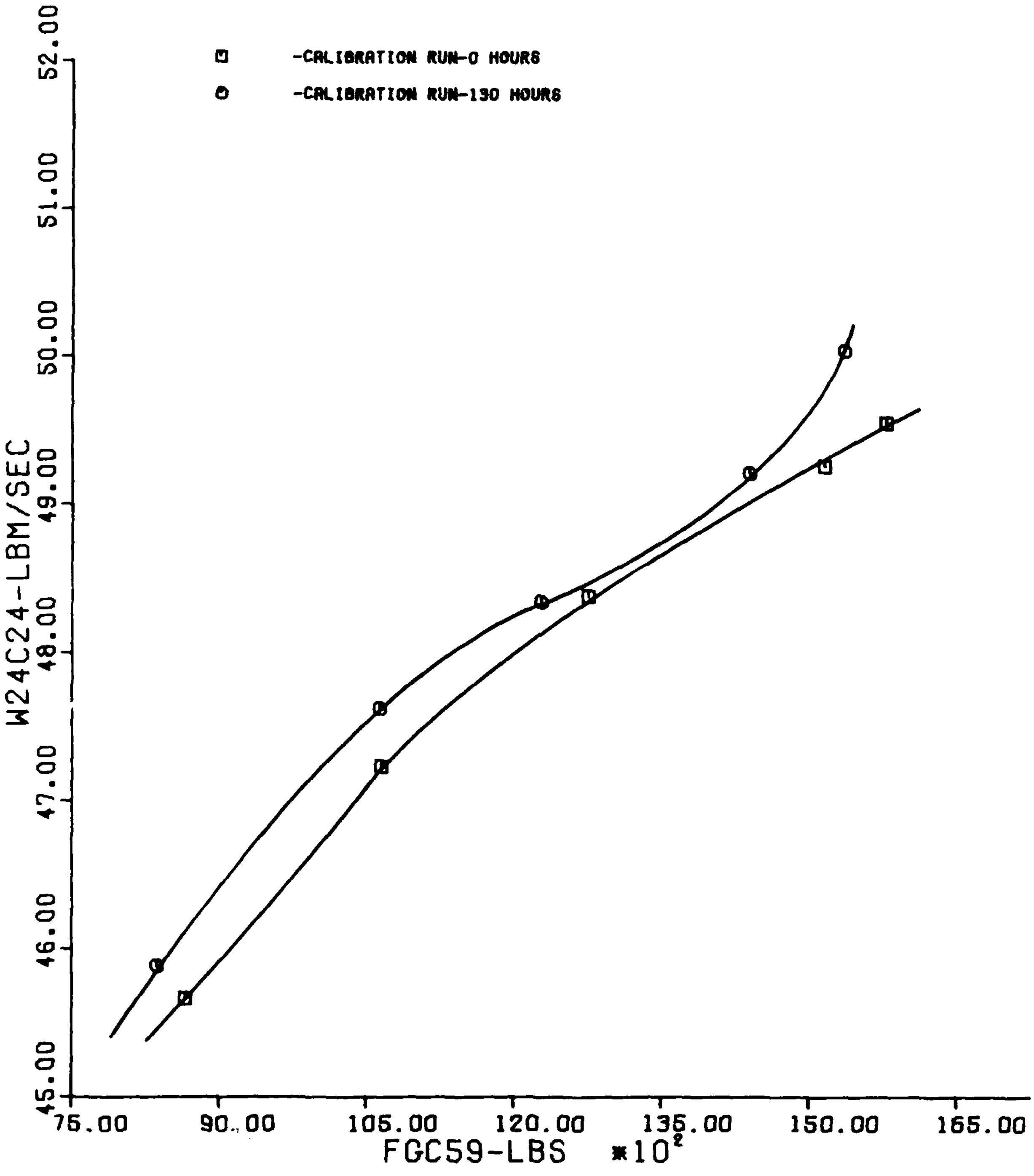


FIGURE 30 - H.P. CORRECTED FLOW VERSUS CORRECTED THRUST

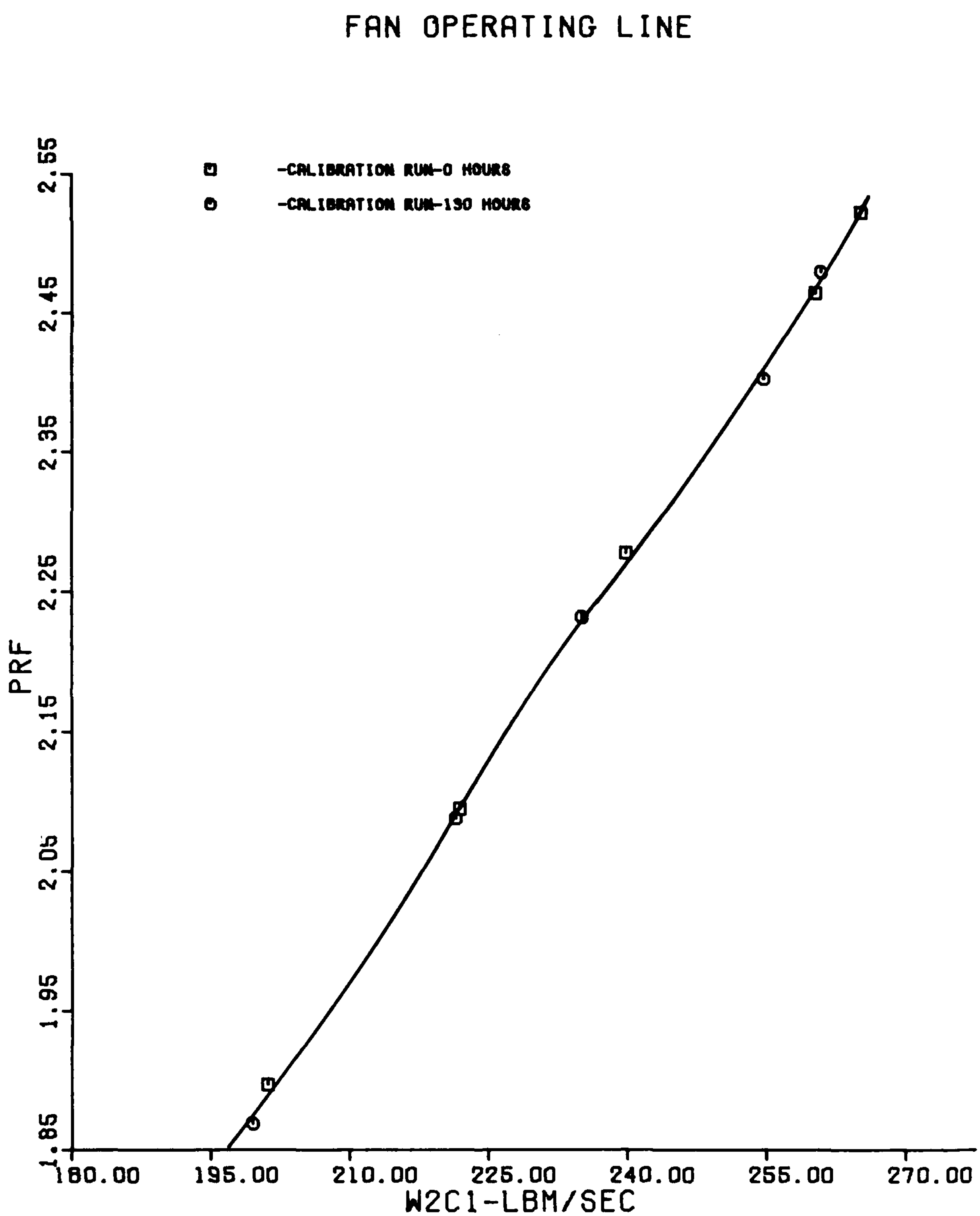


FIGURE 31 - FAN OPERATING LINE

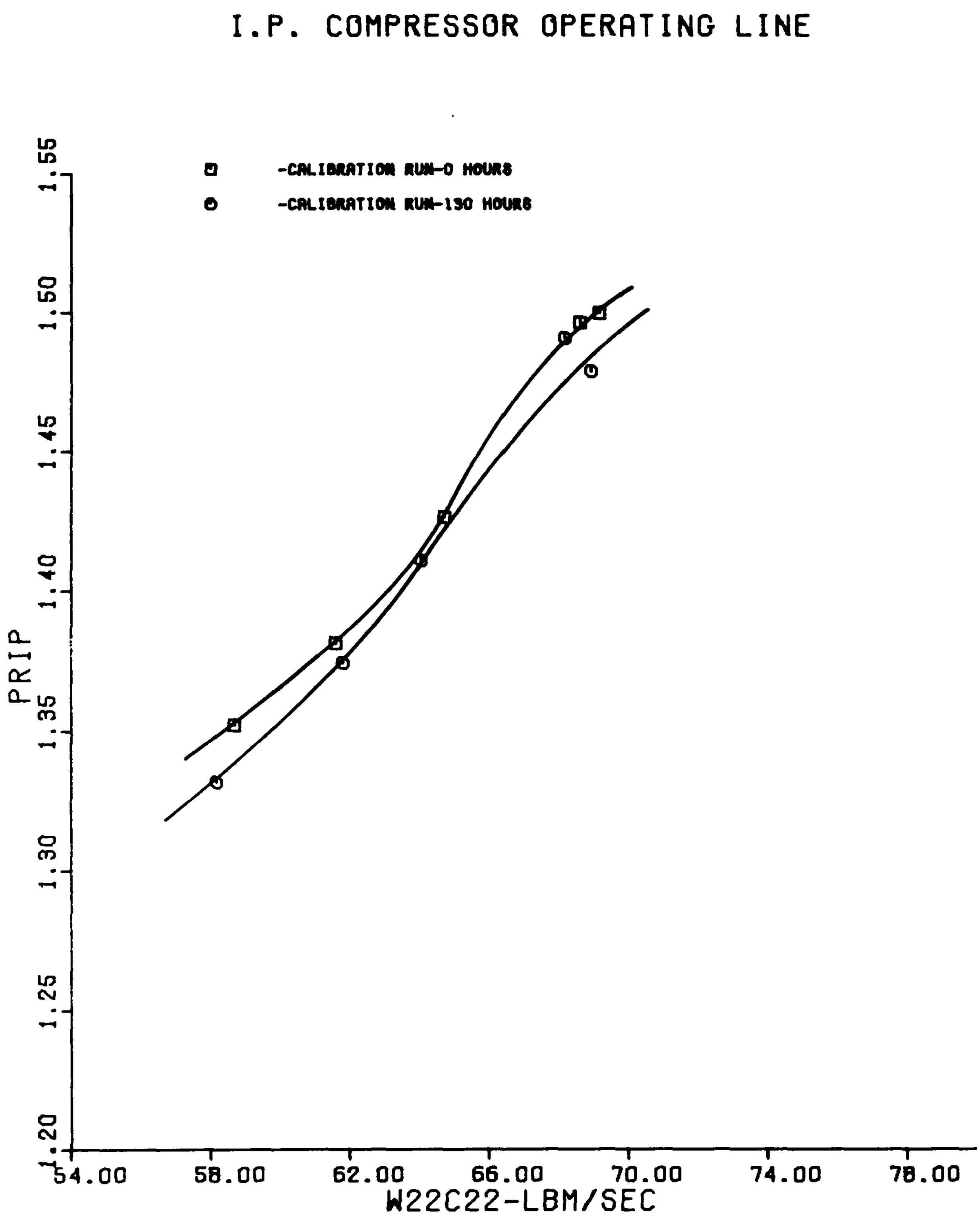


FIGURE 32 - I.P. COMPRESSOR OPERATING LINE

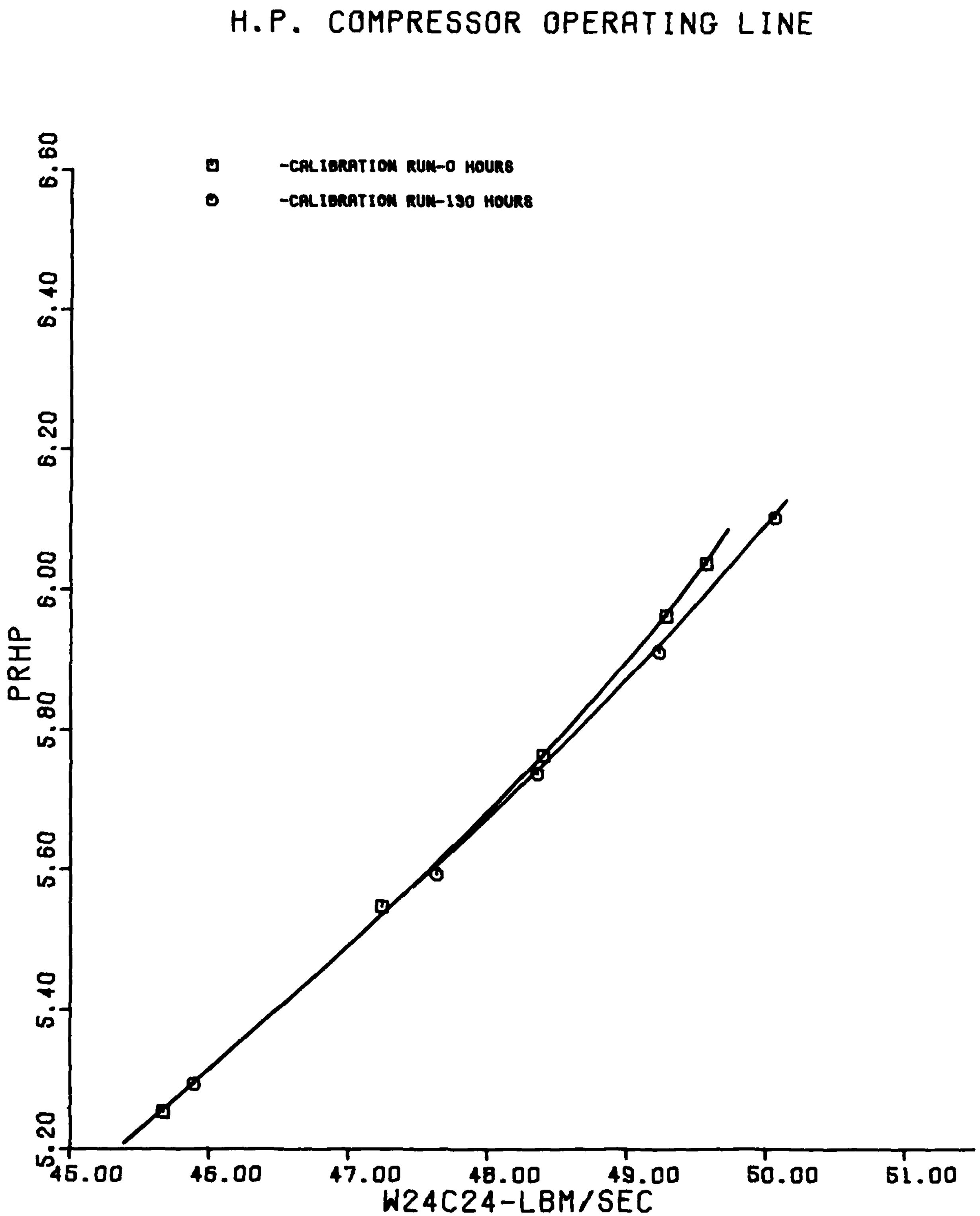


FIGURE 33 - H.P. COMPRESSOR OPERATING LINE

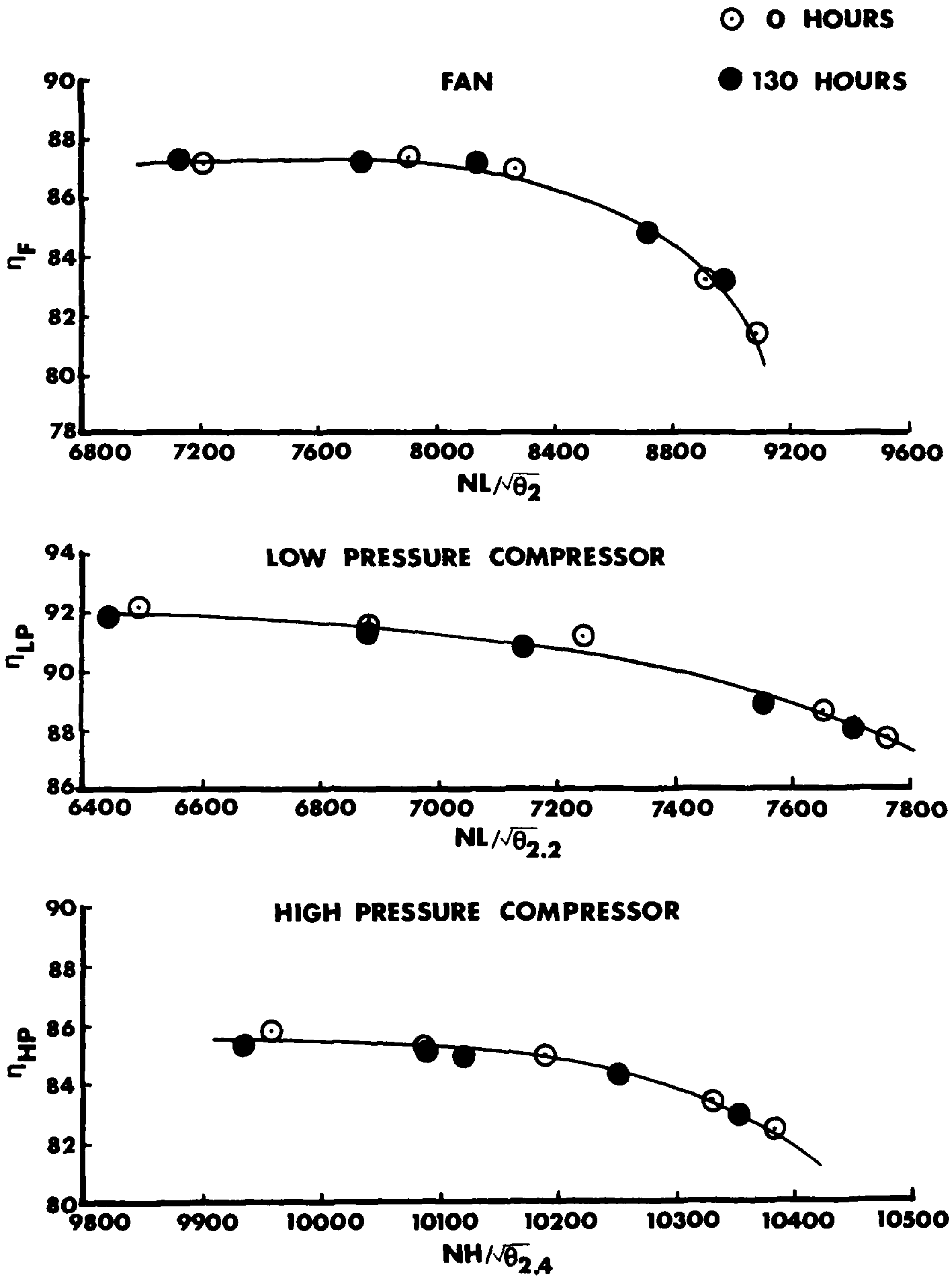


FIGURE 34 - CHANGES IN COMPRESSION SYSTEM PERFORMANCE

Historically, most engine performance deterioration is caused by turbine efficiency losses, especially in the high pressure turbine. Interturbine instrumentation is not available to allow definition of turbine efficiencies. However, based on the assumptions and calculations detailed in Appendix A, estimates of high pressure and low pressure turbine efficiency can be made and are shown as a function of turbine pressure ratio in Figure 35. First of all, these calculated efficiencies show very good agreement with the turbine efficiencies predicted by the steady-state average production TF41 performance simulation (Ref 9) with the exception of the lower values of low pressure turbine pressure ratio. Comparing the data between the 0 and 130 hour power calibration shows that there was less than 1/2% loss in low pressure turbine efficiency and no measurable change in high pressure turbine efficiency.

The steady-state performance calibration data can be used to estimate maximum power performance deterioration. From Figure 24, it appears that for operation at any inlet conditions on the temperature limiter a 1-1/2% reduction in maximum thrust would occur after 130 hours of operation. For inlet conditions resulting in maximum power performance on the mass flow limiter, Figure 18 indicates there would be no thrust loss but Figure 26 shows there would be at least a 1% increase in fuel consumption due to deterioration effects after 130 operating hours.

EXHAUST GAS TEMPERATURE SURVEY

An exhaust gas temperature survey was also run in conjunction with the steady-state performance calibrations at 0 and 100 AMT hours. A 45 thermocouple rake was positioned in the turbine exhaust (Figure 36). A steady-state data point was recorded. The rake was then rotated one tailpipe bolt hole to give a different angular positioning of the probes. This was repeated a total of four times giving a total of 180 temperature readings to map the exhaust gas temperature profile. The results of this survey at 0 and approximately 100 AMT (133 total hours) hours are plotted as isotherms in Figure 37 and 38 (see Ref 10 for details). Table 7 also presents some pertinent data from this analysis. Note that during both EGT surveys the engine was operating on the mass flow limiter and not at maximum exhaust gas temperature. Fortunately, the inlet temperatures during

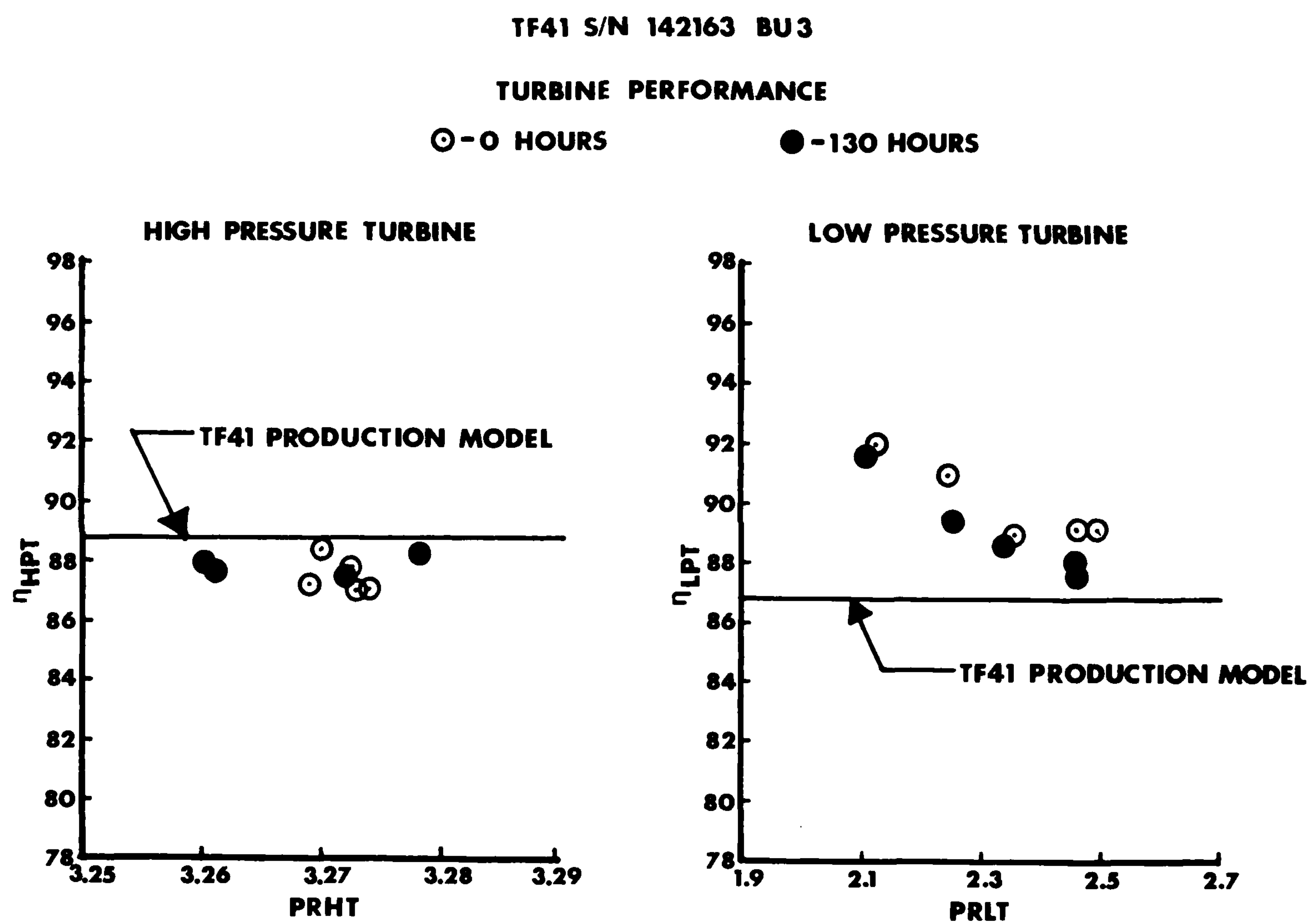


FIGURE 35 - CHANGES IN TURBINE PERFORMANCE

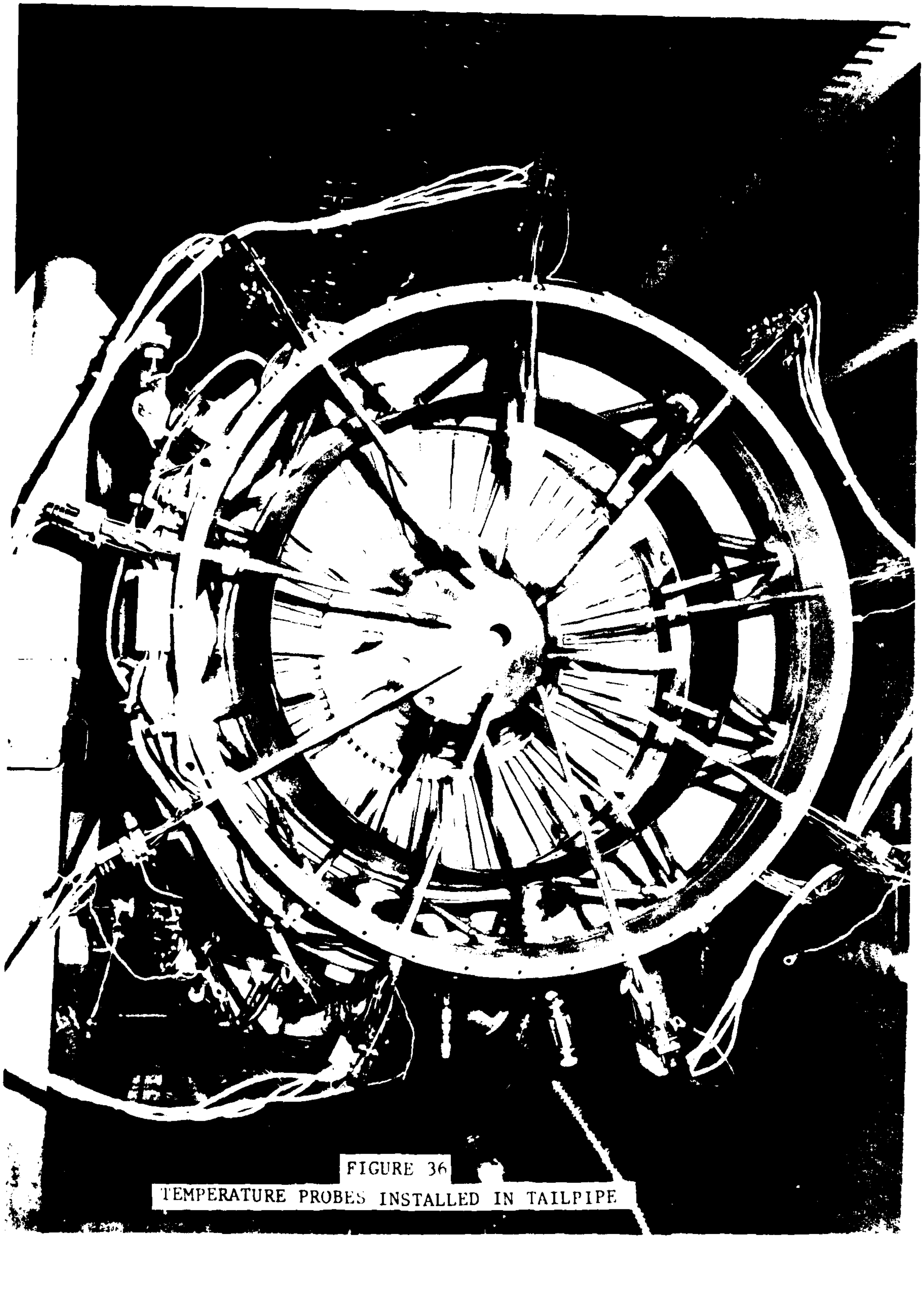


FIGURE 36
TEMPERATURE PROBES INSTALLED IN TAILPIPE

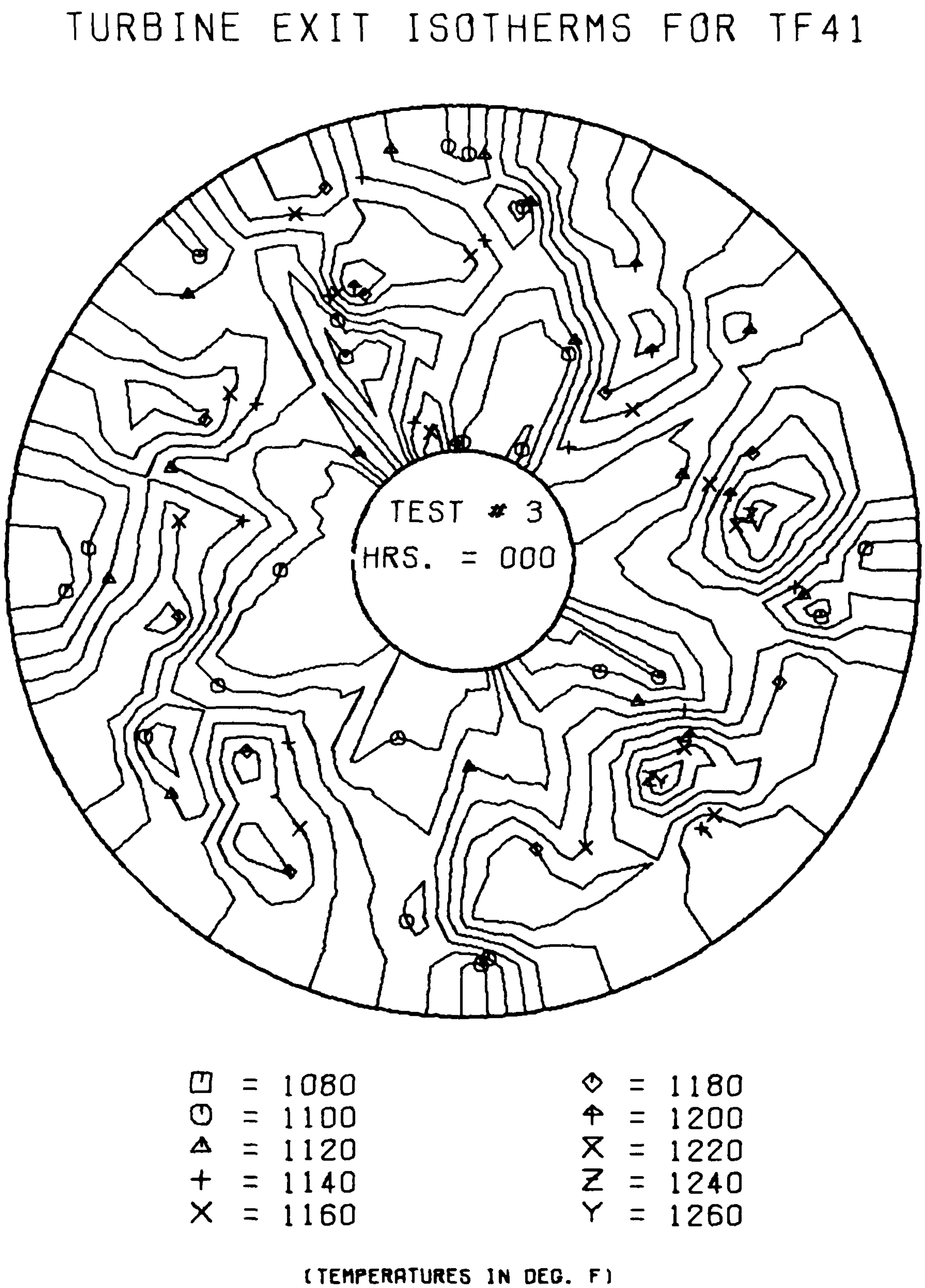
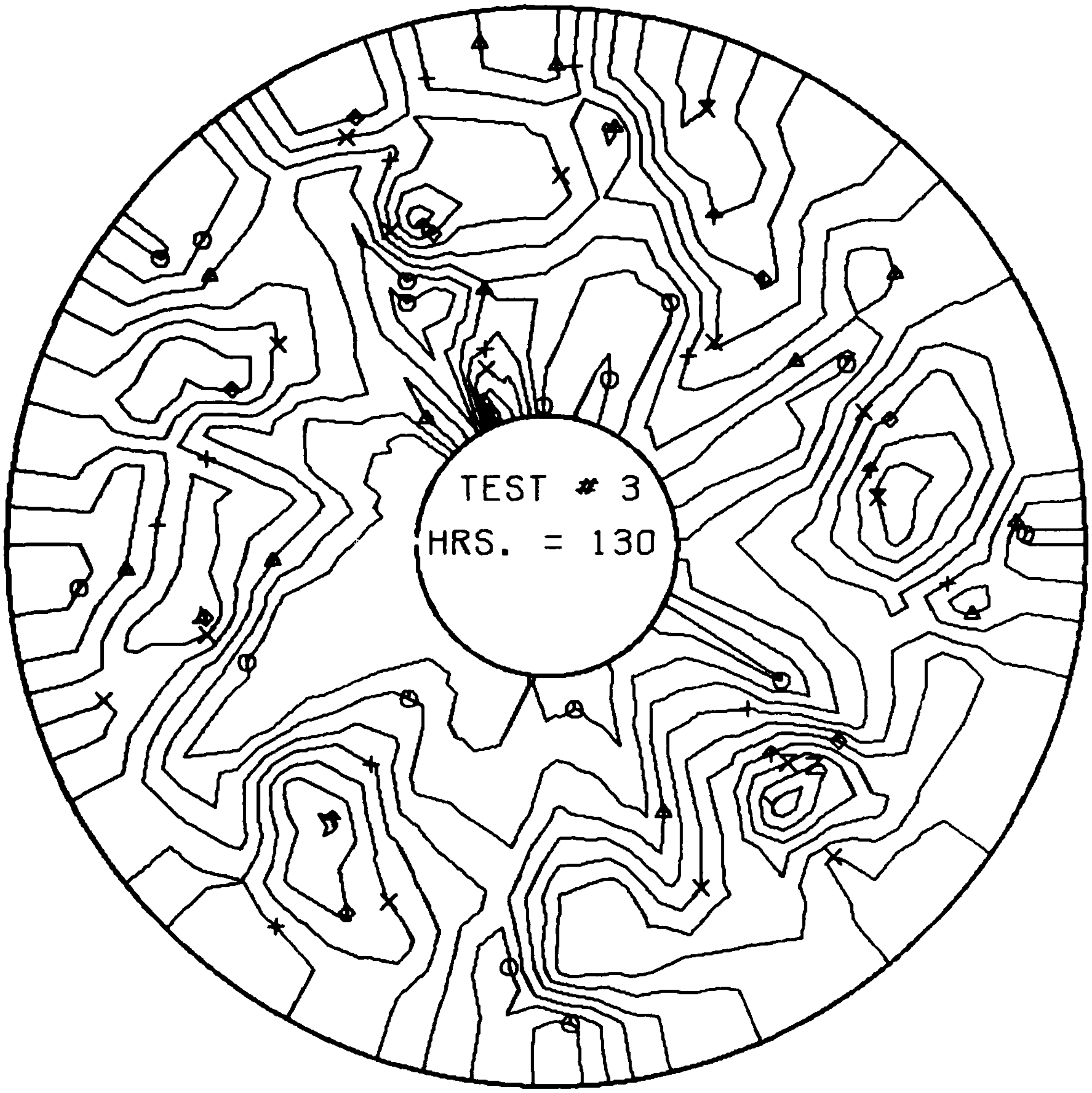


FIGURE 37 - TURBINE EXIT ISOTHERMS, 0 HOURS

TURBINE EXIT ISOTHERMS FOR TF41



□ = 1080		◇ = 1180	
○ = 1100		↑ = 1200	
△ = 1120		X̄ = 1220	
+ = 1140		Z = 1240	
X = 1160		Y = 1260	

(TEMPERATURES IN DEG. F)

FIGURE 38 - TURBINE EXIT ISOTHERMS, 130 HOURS

TABLE 7

EXHAUST GAS TEMPERATURE SURVEY COMPARISON

PARAMETER	BUILD 3		BUILD 2	
	0 HOURS	130 HOURS	0 HOURS	121 HOURS
T5.1 Max	1261.7°F	1275.2°F	1267.3°F	1261.9°F
T5.1 Min	1036.2°F	1040.6°F	1079.3°F	1071.7°F
T5.1 AVG Rake	1133.3°F	1133.2°F	1168.3°F	1166.6°F
T5.1 ENG Harness	1156.8°F	1162.0°F	1174.2°F	1182.7°F

the two surveys differed only by 2°. The data was corrected for this condition and thus the two plots can be compared directly.

Some interesting observations can be made from these plots. First of all, there does not appear to be any significant shift in profile as a function of engine operating time. The magnitude of the maximum temperature increased only 14° and its location did not change as the engine deteriorated. This would imply that deterioration in the burner and upstream components is not affecting the burner exit temperature profile. Making the simple assumption of a uniform constant temperature drop across the turbine, the data indicates there will be almost a 230°F spread in burner exit temperature. In other words, at a calculated average burner exit temperature of 2165°F, temperatures in excess of 2280°F would exist at some locations behind the burner.

Comparing the results from this survey with the results from the survey performed during the AMT of the second build of this engine (Ref 2) shows some interesting results (Table 7). First of all, the magnitude of the maximum exhaust gas temperature reading was approximately the same. However, Build 3 was operating on the mass flow limiter and at a reduced average exhaust gas temperature relative to Build 2 which was operating on the exhaust gas temperature limit. It can be inferred then, that Build 3 would have a significantly higher peak exhaust gas temperature than Build 2 when both were operating on the temperature limiter. Another difference between the two builds is in the magnitude of the temperature spread between maximum and minimum. Build 3 showed a difference of about 230°F while Build 2 had only about a 188°F spread. Also, the difference between the rake average exhaust gas temperature and the engine harness thermocouple average was more pronounced for Build 3 than Build 2. In summary, it appears that deterioration related effects on exhaust gas temperature profile are minimal but for some reason, there is a difference between the Build 2 and the Build 3 temperature profiles.

SECTION IX

RESULTS OF TEARDOWN INSPECTION AND FAILURE ANALYSIS

After approximately 133 AMT hours during a snap accel from idle to intermediate during the 184th "A" cycle turbine vibration spiked up over 5.0 mils. The engine was immediately shutdown. Borescope inspections by both AFAPL and Allison personnel did not reveal any significant gas path damage. The engine was motored on the starter and when operation and coastdowns appeared normal it was started. Again, near intermediate power turbine vibration exceeded limits and the engine was shutdown. It was removed from the cell and returned to Allison for a failure investigation.

At Allison, the engine was torn down to its major modules. The details of the teardown inspection are contained in Appendix C. A brief summary of the major findings follows:

- Fan
  - ° first stage stop plate broken (Figures 39 and 40).
- HP Compressor
  - ° bearing wear (probable cause of debris in oil)
  - ° wear on OGV and at 7th stage bleed valve
- Combustor
  - ° heavy erosion on smoke chutes
  - ° heavy fretting on nozzle flanges
  - ° cracks in crossover tubes
  - ° cracks and burn holes in nozzle
- HP Turbine
  - ° heavy rub damage on seals and blades
  - ° cracks in 2nd stage vanes
  - ° FOD leading edge 1st stage blades
  - ° cracks and erosion in 1st stage vanes
- LP Turbine
  - ° heavy rub and wear on seals and blades

FAILURE ANALYSIS

The primary cause of engine failure was the broken first stage low pressure compressor stop plate (Fig 39 and 40). An analysis was conducted

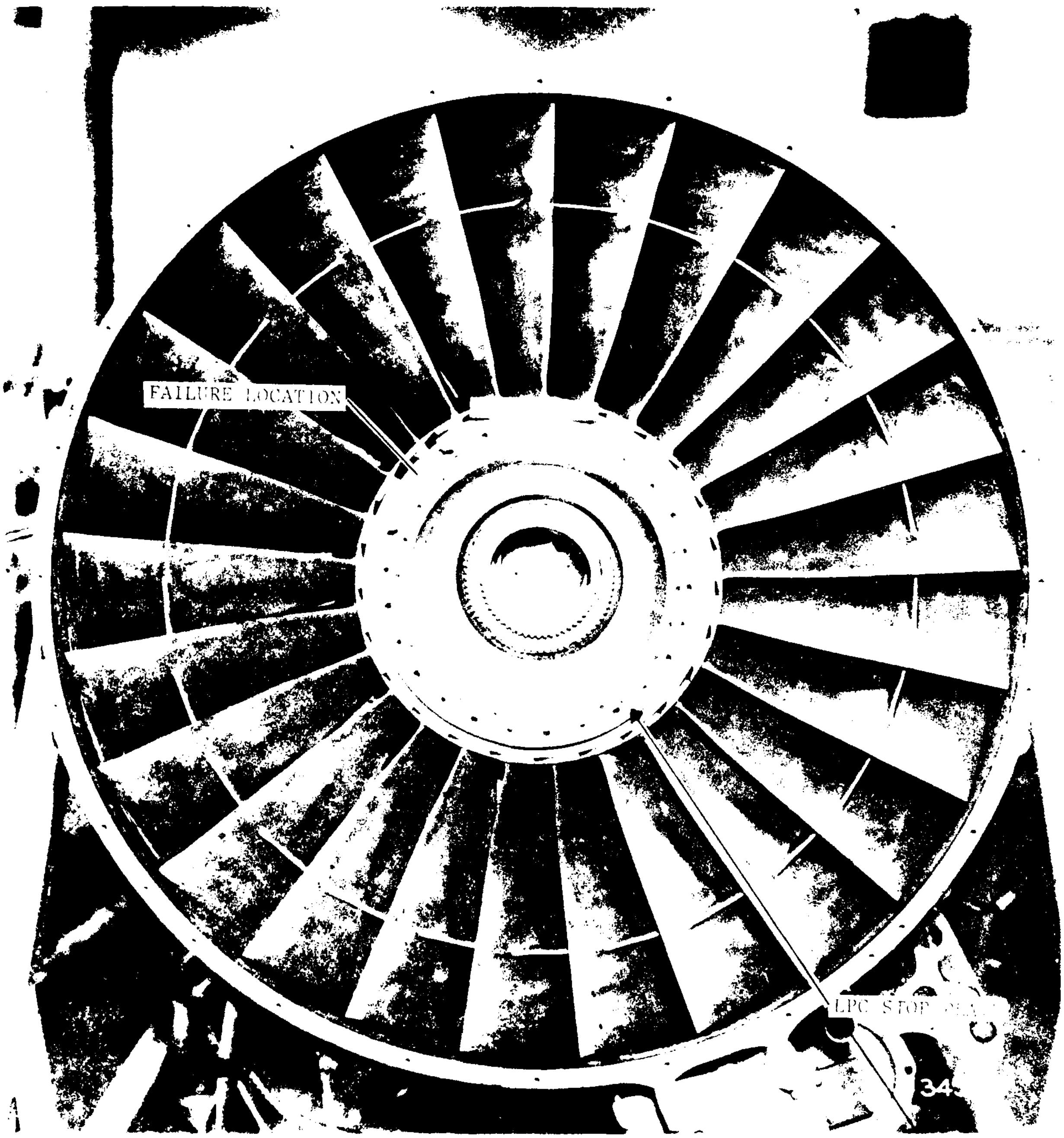
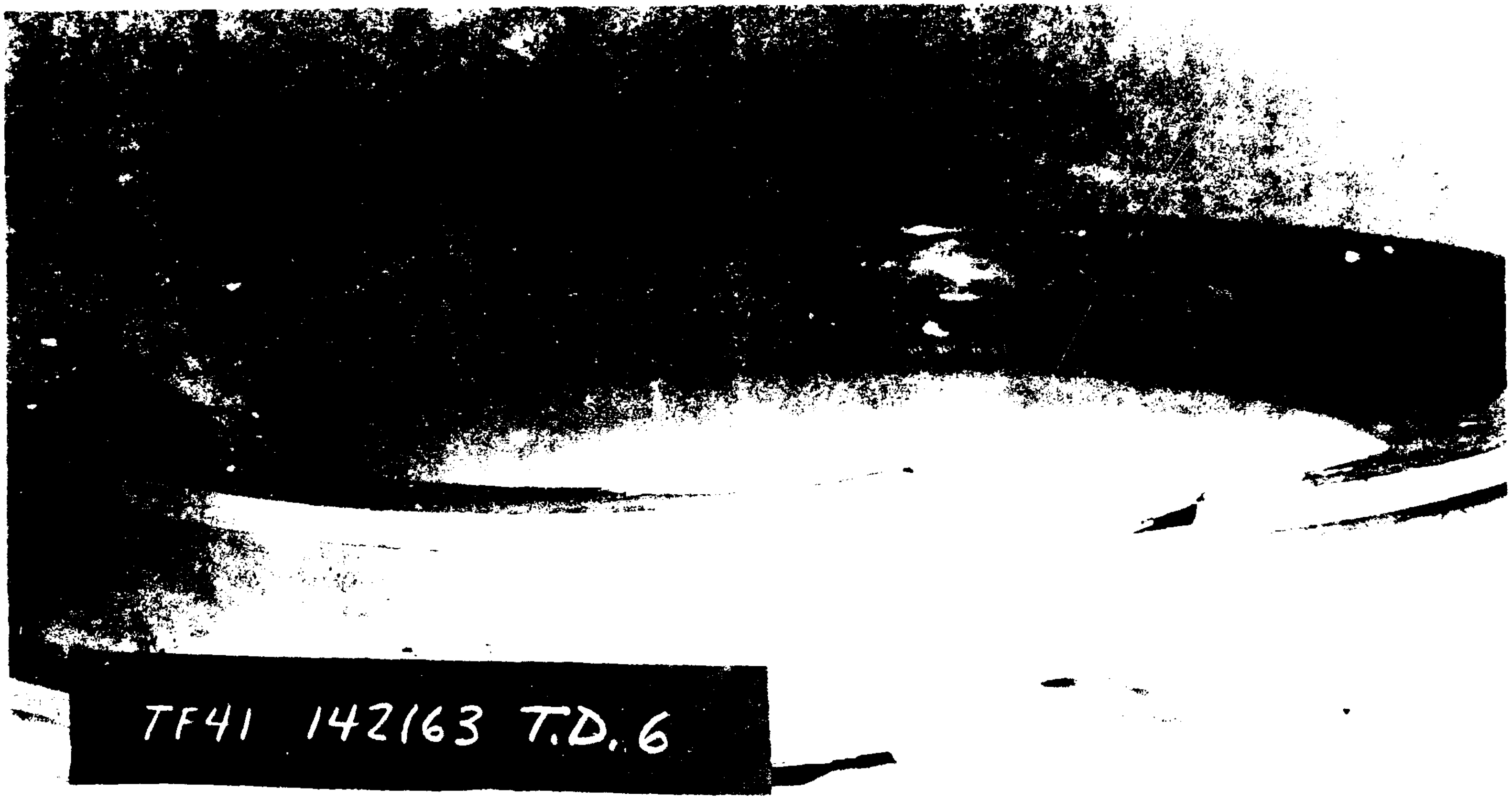


FIGURE 30 - FIRST STAGE LOW PRESSURE COMPRESSOR


TF41 142163 T.D.6

by Allison's Material Engineering Group and the conclusion was that the failure originated in stress corrosion at the aft flange surface adjacent to the OD of this flange. Secondary fatigue originated at the base of the intergranular fracture area. Stress corrosion was also present on several areas of the aft flange (Ref 11).

Scanning electron microscope fractographs showed damage on the OD surface and distorted machine tool marks on the aft face adjacent to the intergranular failure. The fractographs also showed the fatigue failure adjacent to the aft face originating from the intergranular fracture and fatigue striations progressing away from the failure origin area.

Microexamination of the OD rim flange showed secondary mechanical damage adjacent to the failure surface. Microexamination of a transverse section through the failure origin area showed intergranular failure with corrosion at the grain boundaries at the aft face origin and transgranular fatigue progressing from it. The corrosion was intergranular in nature indicative of stress corrosion.

The stop plate was manufactured using AMS 4132. The hardness of the material conformed to the minimum requirements and a spectrographic analysis of the material from the stop plate showed conformance to the required chemical composition of AMS 4132.

The first stage low pressure compressor stop plate which failed in 142163 had an unknown history from the time of manufacture until November 1973. Since this time, the part accumulated over 1011 AMT test hours.

All the other teardown findings were considered to be normal wear for the amount of time on the parts or secondary damage as a result of the stop plate failure. Therefore, they were not investigated in great detail.

SECTION X
SUMMARY AND CONCLUSIONS

An accelerated mission test of a TF41-A-1 engine S/N 142163 was run at the Air Force Aero Propulsion Laboratory's D-Bay sea level engine test facility. The objectives were to continue to test the durability of a set of hardware modifications known as "Block 76" hardware, to verify the reliability of several rework and part repair schemes, to verify the durability of an experimental set of aircooled second stage turbine blades, to track and document overall engine performance deterioration and investigate burner outlet temperature profile changes. The test was initially scheduled for 263 hours but was prematurely terminated after 133 AMT hours (148 total engine operating hours) due to the failure of a first stage low pressure compressor stop plate.

The engine was returned to Allison for a teardown inspection. The failure was the result of stress corrosion at the aft flange adjacent to the OD surface of the first stage low pressure compressor stop plate. Several other areas of stress corrosion were also discovered in the aft flange area. This part had accumulated 1011 AMT hours after November 1973 and the time history prior to this date was unknown.

In general, the "Block 76" hardware performed very well and was not a factor in the engine's failure. Many of the first stage vanes showed some cracks and distress but this was considered normal wear for the equivalent amount of running time. Most of these vanes had been run in previous AMT tests and had accumulated more than 450 AMT hours of operation.

None of the reworked or repaired parts showed indications of unusual distress. The aircooled second stage turbine blades also appeared to be in excellent condition. These blades will undergo further AMT testing. The other items noted in the teardown inspection report were either considered normal wear and tear or are secondary damage caused by the high vibration following the first stage low pressure compressor stop plate failure.

Deterioration effects were difficult to quantify using the "A" cycle data due to the reduced test time. This was compounded by the lack of consistency in available data due to varying inlet temperature, customer

bleed flow, and mass flow limiter setting. Analysis of the steady-state power calibration data indicated a 1-1/2% reduction in maximum thrust for operation on the exhaust gas temperature limit after 130 operating hours. The same data showed that for operation on the mass flow limiter (i.e., cold day) maximum thrust did not change with engine operating time but fuel consumption increased by 1% due to deterioration.

Exhaust gas temperature surveys were performed at 0 and 100 AMT hours. Analysis of this data indicates that there was no significant shift in profile with increasing operating time. The magnitude of the hot spot increased only slightly and its location remained unchanged. This would imply that there is no significant shift in burner exit temperature profile as the engine deteriorated.

The original plan for testing the "Block 76" hardware included 526 hours of AMT testing in two builds, separated by a teardown and overhaul. This was the third failure that occurred on this engine while AMT testing, none of which was related to the "Block 76" parts. Only 428 AMT test hours have been completed. However, the engine will not be rebuilt for further AMT testing and this concludes the program.

APPENDIX A PERFORMANCE CALCULATIONS

APPENDIX A

SYMBOLS

SYMBOL	NAME	SOURCE	UNITS
A4	Turbine inlet nozzle area	Constant	IN^2
ABLEED	Bleed port area	Constant	IN^2
ASCRN	Inlet FOD screen area	Constant	-
CPFG	Specific heat correction/thrust	Calculated	-
CPN	Specific heat correction/speed	Calculated	-
CPP21	Specific heat correction/P21	Calculated	-
CPP23	Specific heat correction/P23	Calculated	-
CPP3	Specific heat correction/P3	Calculated	-
CPP5	Specific heat correction/P5	Calculated	-
CPT21	Specific heat correction/T21	Calculated	-
CPT23	Specific heat correction/T23	Calculated	-
CPT3	Specific heat correction/T3	Calculated	-
CPT5	Specific heat correction/T5	Calculated	-
CPWA	Specific heat correction/airflow	Calculated	-
CPWF	Specific heat correction/fuel flow	Calculation	-
CVPFG	Humidity correction/thrust	Calculated	-
CVPN	Humidity correction/speed	Calculated	-
CVPP21	Humidity correction/P21	Calculated	-
CVPP23	Humidity correction/P23	Calculated	-
CVPP3	Humidity correction/P3	Calculated	-
CVPP5	Humidity correction/P5	Calculated	-
CVPT21	Humidity correction/T21	Calculated	-
CVPT23	Humidity correction/T23	Calculated	-
CVPT3	Humidity correction/T3	Calculated	-
CVPT5	Humidity correction/T5	Calculated	-
CVPWA	Humidity correction/airflow	Calculated	-
CVPWF	Humidity correction/fuel flow	Calculated	-
EPR	Engine pressure ratio	Calculated	-
FGM	Measured thrust	Measured	LB_F
FG	Thrust	Calculated	LB_F
FSCRN	Inlet FOD screen force	Calculated	LB_F
H1	Engine inlet enthalphy	Table Look Up	BTU/LBM

APPENDIX A

SYMBOLS (Cont'd)

SYMBOL	NAME	SOURCE	UNITS
H21H	Fan hub exit enthalpy	Table Look Up	BTU/LBM
H21HI	Fan hub ideal exit enthalpy	Table Look Up	BTU/LBM
H21T	Fan tip exit enthalpy	Table Look Up	BTU/LBM
H21TI	Fan tip ideal exit enthalpy	Table Look Up	BTU/LBM
H22	I.P. compressor exit enthalpy	Table Look Up	BTU/LBM
H22I	I.P. compressor ideal exit enthalpy	Table Look Up	BTU/LBM
H23	H.P. compressor inlet enthalpy	Table Look Up	BTU/LBM
H3	H.P. compressor discharge enthalpy	Table Look Up	BTU/LBM
H3I	Ideal H.P. compressor discharge enthalpy	Calculated	BTU/LBM
H4	H.P. turbine inlet enthalpy	Calculated	BTU/LBM
H41	H.P. turbine rotor inlet enthalpy	Calculated	BTU/LBM
H42	H.P. turbine exit enthalpy	Calculated	BTU/LBM
H42I	L.P. turbine ideal inlet enthalpy	Calculated	BTU/LBM
H43	L.P. turbine inlet enthalpy	Calculated	BTU/LBM
H5	Untrimmed exhaust gas enthalpy	Table Look Up	BTU/LBM
H5I	Ideal turbine exit enthalpy	Calculated	BTU/LBM
HF4	Enthalpy of the fuel	Table Look Up	BTU/LBM
LHV	Fuel lower heating value	Constant	BTU/LBM
NH	HP rotor speed	Calculated	RPM
NHM	Measured HP rotor speed	Measured	RPM
NL	LP rotor speed	Calculated	RPM
NLM	Measured rotor speed	Measured	RPM
OPR	Overall compressor pressure ratio	Calculated	-
PAMB	Ambient pressure	Measured	IN HG
P1	Engine inlet total pressure	Measured	PSIA
P21H	Fan hub exit pressure	Calculated	PSIA
P21T	Fan tip exit pressure	Calculated	PSIA
P21M	Measured fan exit pressure	Measured	PSIG
P22	I.P. compressor exit pressure	Calculated	PSIA
P23	H.P. compressor inlet pressure	Calculated	PSIA
P23M	Measured H.P. compressor inlet pressure	Measured	PSIG

APPENDIX A
SYMBOLS (Cont'd)

SYMBOL	NAME	SOURCE	UNITS
P3	Compressor discharge total pressure	Calculated	PSIA
P4	Turbine inlet total pressure	Calculated	PSIA
P43	L.P. turbine inlet pressure	Calculated	PSIA
P5M	Measured exhaust gas total pressure	Measured	PSIG
P5	Exhaust gas total pressure	Calculated	PSIA
PRFH	Fan hub pressure ratio	Calculated	-
PRFT	Fan tip pressure ratio	Calculated	-
PRHP	H.P. compressor pressure ratio	Calculated	-
PRHPT	H.P. turbine pressure ratio	Calculated	-
PRIP	I.P. compressor pressure ratio	Calculated	-
PRLP	L.P. compressor pressure ratio	Calculated	-
PRLPT	L.P. turbine pressure ratio	Calculated	-
PRT	Overall turbine pressure ratio	Calculated	-
PS1	Bellmouth static pressure	Measured	PSIA
PS3	Compressor discharge static pressure	Measured	PSIG
RES	T5 Ballast resistance	Constant	OHMS
RH	T5 thermocouple harness resistance	Constant	OHMS
SFC	Specific fuel consumption	Calculated	LBM/HR/LBF
SGF	Fuel specific gravity	Constant	-
SGFM	Calibrated specific gravity of flow meter	Constant	-
SGFT	Fuel specific gravity at fuel tank	Measured	-
T1	Engine inlet total temperature	Measured	°F
T21H	Fan hub exit temperature	Calculated	°F
T21T	Fan tip exit temperature	Calculated	°F
T21M	Measured fan exit temperature	Measured	°F
T22	I.P. compressor exit temperature	Calculated	°F
T23	H.P. compressor inlet temperature	Calculated	°F
T23M	Measured H.P. compressor inlet temperature	Measured	°F
T3M	Measured compressor discharge total temperature	Measured	°F

APPENDIX A
SYMBOLS (Cont'd)

SYMBOL	NAME	SOURCE	UNITS
T3	Compressor discharge total temp	Calculated	°F
T4	Turbine inlet total temperature	Calculated	°F
T43	L.P turbine inlet temperature	Calculated	°F
T5M	Measured trimmed exhaust gas temp	Measured	°F
T5	Trimmed exhaust gas total temp	Calculated	°F
T5UT	Untrimmed exhaust gas total temp	Calculated	°F
TFUEL	Fuel temp at engine	Measured	°F
TFUELT	Fuel temp at tank	Measured	°F
TPR	Overall turbine pressure ratio	Calculated	-
TJB	Junction box temperature	Measured	°F
TJBS	Standard junction box temp	Constant	°F
V_P	Vapor pressure	Table Look Up	IN HG
WA	Engine inlet airflow	Calculated	LBM/SEC
WA22	Engine core airflow	Calculated	LBM/SEC
WA4	Turbine inlet airflow	Calculated	LBM/SEC
WAI	Total corrected engine inlet airflow	Calculated	LBM/SEC
WBLEED	11th stage bleed flow	Calculated	LBM/SEC
WFCS	Fuel flow corrected for specific gravity	Calculated	LBM/SEC
WFM	Measured fuel flow	Measured	LBM/HR
WF	Fuel flow	Calculated	LBM/HR
WG4	Turbine inlet gas flow	Calculated	LBM/SEC
ΔP	Bellmouth pressure differential	Calculated	IN H_2O
ΔP_B	Burner pressure drop	Constant	-
δ	Inlet pressure correction	Calculated	-
θ	Inlet temperature correction	Calculated	-
θ^*	Inlet temperature correction/T5	Calculated	-
η_B	Burner efficiency	Constant	-
η_C	Overall compressor efficiency	Calculated	-
η_{FH}	Fan hub efficiency	Calculated	-
η_{FT}	Fan tip efficiency	Calculated	-

APPENDIX A

SYMBOLS (Cont'd)

SYMBOL	NAME	SOURCE	UNITS
η_{HP}	H.P. compressor efficiency	Calculated	-
η_{HPT}	H.P. turbine efficiency	Calculated	-
η_{IP}	I.P. compressor efficiency	Calculated	-
η_{LP}	L.P. compressor efficiency	Calculated	-
η_{LPT}	L.P. turbine efficiency	Calculated	-
η_{T}	Overall turbine efficiency	Calculated	-

CORRECTION OF MEASURED PARAMETERS

Most of the engine parameters measured during the test must be corrected for several different effects. These effects include the standard inlet temperature and pressure corrections as well as empirically derived corrections for humidity, specific heat, instrumentation, and installation effects. The expressions for these correction factors were obtained from Technical Order 2J-TF41-3. The procedure for correcting the data is outlined below. Note that corrections can be made for a standard temperature of 59°F or 77°F.

Inlet Condition Corrections

TSTD = 518.7 or 536.7°R

= T1/TSTD

= P1/14.696

Humidity Corrections

$$HUM = 4353.2\left(\frac{V_P}{PAMB-V_P}\right)$$

CVPFG = 1.0 + .0000143 x HUM

CVPN = 1.0 - .0000343 x HUM

CVPWA = 1.0 + .0000457 x HUM

CVPWF = 1.0 - .0000814 x HUM

CVPP21 = 1.0

CVPP23 = 1.0

CVPP3 = 1.0

CVPP5 = 1.0 + .0000079 x HUM

CVPT21 = 1.0 + .0000107 x HUM

CVPT23 = 1.0 + .0000143 x HUM

CVPT3 = 1.0 + .00003 x HUM

CVPT5 = 1.0 - .0000264 x HUM

C_P Corrections

CPFG = 1.0 - .0001214 (T1-TSTD)

CPN = 1.0

CPWA = 1.0

CPWF = 1.0 - .0003846 (T1-TSTD)

CPP21 = 1.0 - .0000806 (T1-TSTD)

CPP23 = 1.0 - .0000806 (T1-TSTD)

CPP3 = 1.0 - .0000645 (T1-TSTD)

CPP5 = 1.0 - .000071 (T1-TSTD)

CPT21 = 1.0 - .0000065 (T1-TSTD)

CPT23 = 1.0 - .0000097 (T1-TSTD)

CPT3 = 1.0 + .0001355 (T1-TSTD)

CPT5 = 1.0 - .000071 (T1-TSTD)

CORRECTED PARAMETER CALCULATIONS

Thrust

During the test, the engine is mounted on a thrust stand. The measured scale force is displayed on the CRT and recorded on the line printer. However, in the "D"-Bay installation, the inlet FOD screen is mounted on the thrust balance. Therefore, the displayed thrust includes the screen drag which must be accounted for. This loss can be estimated by assuming ambient pressure on the upstream side of the screen and engine inlet total pressure on the downstream side with no change in velocity across the screen. The screen force can be calculated as:

$$FSCRN = ASCRN \times (PAMB-P1) \qquad (1)$$

Thrust must also be corrected for humidity, CP, and inlet pressure effects according to the following equation:

$$\frac{FG}{\delta} = \frac{(FGM + FSCRN) \times CVPFG \times CPFG}{\delta} \qquad (2)$$

Fuel Flow

A flow meter is installed in the fuel line ahead of the engine and its output is displayed on the CRT and recorded on the line printer. However, the flow meter is calibrated for only one fuel specific gravity (.762 in this case). The actual specific gravity is a function of both fuel temperature and the particular batch of fuel being used. The displayed fuel flow must be corrected for specific gravity effects using the following equations:

$$SGF = SGFT - .0004 \times (TFUEL - TFUELT) \qquad (3)$$

$$WFCS = WFM \times \left(\frac{SGF}{SGFM}\right) \qquad (4)$$

This fuel flow is then corrected for humidity, CP, inlet temperature and and pressure, and lower heating value effects according to the following equation:

$$\frac{WF}{\sqrt{\theta}\delta} = \frac{WFCS \times CVPWF \times CPWF \times \frac{LHV}{18400}}{\delta\sqrt{\theta}} \tag{5}$$

HIGH PRESSURE ROTOR SPEED

The high pressure rotor tach reading must be corrected for humidity and inlet temperature effects.

$$\frac{NH}{\sqrt{\theta}} = \frac{NHM \times CVPN}{\sqrt{\theta}} \tag{6}$$

LOW PRESSURE ROTOR SPEED

The low pressure rotor tach reading must be corrected for humidity and inlet temperature effects.

$$\frac{NL}{\sqrt{\theta}} = \frac{NLM \times CVPN}{\sqrt{\theta}} \tag{7}$$

HIGH PRESSURE COMPRESSOR DISCHARGE PRESSURE

The measured variable at this station is a static pressure which must be converted to a total pressure. It must also be corrected for specific heat, inlet pressure, and instrumentation.

$$\frac{P3}{\delta} = \left[\left(\frac{PS3}{\delta} \times CPP3\right) + 4.56\right] \times 1.0512 \tag{8}$$

EXHAUST GAS PRESSURE

The measured exhaust gas pressure must be corrected for humidity, CP, and inlet pressure effects.

$$\frac{P5}{\delta} = \frac{P5M \times CVPP5 \times CPP5}{\delta} \tag{9}$$

HIGH PRESSURE COMPRESSOR DISCHARGE TEMPERATURE

The measured high pressure compressor discharge temperature must be corrected for humidity, CP, inlet temperature, and instrumentation effects.

$$\frac{T3}{\theta} = \left[\left(\frac{T3M + 459.7}{\theta} \times CVPT3 \times CPT3\right) + 1.2\right] \times 1.003 - 459.7 \tag{10}$$

EXHAUST GAS TEMPERATURE

The measured exhaust gas temperature must be corrected for humidity and CP effects. In addition, it must be adjusted to a standard junction box temperature and corrected for the ballast and harness resistance. A non-standard inlet temperature correction ($\theta^{.8788}$) is also used because TF41 past history has shown it correlates the data better.

$$\frac{T5}{\theta^*} = \left(\left[T5m \times \left(1.0 + \frac{RH}{RES}\right)\right] - \left(\frac{RH}{RES} \times TJB\right) + \left(\left[459.7 \times (1.0 - \theta^*)\right] + \left[\frac{RH}{RES} \times \theta^* \times TJBS\right]\right) \div \left(\left[1.0 + \frac{RH}{RES}\right] \times \theta^*\right)\right) \quad (11)$$

where:

$$* = \frac{\theta^{.8788}}{CVPT5 \times CPT5} \quad (12)$$

AIRFLOW

The calculated airflow is already corrected for inlet pressure and temperature effects but must still be corrected for humidity.

$$\frac{WA\sqrt{\theta}}{\delta} = WAI \times CVPWA \quad (13)$$

FAN TIP DISCHARGE PRESSURE

The measured fan tip discharge pressure must be corrected for specific heat, inlet pressure, and instrumentation.

$$\frac{P21T}{\delta} = \left[\left(\frac{P21M}{\delta} \times CPP21\right) + 1.19\right] \times .9911 \quad (14)$$

FAN HUB DISCHARGE PRESSURE

This measured variable is fan tip discharge pressure and this must be converted to the hub discharge pressure. It must also be corrected for specific heat and inlet pressure.

$$\frac{P21H}{\delta} = \left[\left(\frac{P21M}{\delta} \times Cpp21\right) + 4.14\right] \times .95 \quad (15)$$

INTERMEDIATE PRESSURE COMPRESSOR DISCHARGE PRESSURE

The measured intermediate pressure compressor discharge pressure must be corrected for specific heat, inlet pressure, and instrumentation.

$$\frac{P22}{\delta} = \left[\left(\frac{P23M}{\delta} \times CPP23\right) + 1.41\right] \times .9776 \tag{16}$$

HIGH PRESSURE COMPRESSOR INLET PRESSURE

The measured variable is intermediate pressure compressor discharge pressure and this must be converted to the high pressure compressor inlet pressure. It must also be corrected for specific heat and inlet pressure.

$$\frac{P23}{\delta} = \left[\left(\frac{P23M}{\delta} \times CPP23\right) + 3.38\right] \times .9413 \tag{17}$$

FAN TIP DISCHARGE TEMPERATURE

The measured fan tip discharge temperature must be corrected for humidity, specific heat, inlet temperature, and instrumentation.

$$\frac{T21T}{\theta} = \left[\left(\frac{T21M + 459.7}{\theta} \times CPT21 \times CVPT21\right) + 68.1\right] \times .9028 \tag{18}$$

FAN HUB DISCHARGE TEMPERATURE

The measured variable is fan tip discharge temperature which must be converted to fan hub discharge temperature. It must also be corrected for humidity, specific heat, and inlet temperature.

$$\frac{T21H}{\theta} = \left[\left(\frac{T21M + 459.7}{\theta} \times CPT21 \times CVPT21\right) + 200.8\right] \times .76 \tag{19}$$

INTERMEDIATE PRESSURE COMPRESSOR DISCHARGE TEMPERATURE

The measured intermediate pressure compressor discharge temperature must be corrected for humidity, specific heat, inlet temperature and instrumentation.

$$\frac{T22}{\theta} = \left[\left(\frac{T23M + 459.7}{\theta} \times CPT23 \times CVPT23\right) - 58.7\right] \times 1.0895 \tag{20}$$

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BUILD 3 OF AN ACCELERATED MISSION TEST OF A TF41 WITH BLOCK 76 --ETC(U)
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UNCLASSIFIED AFAPL-TR-79-2123 NL

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HIGH PRESSURE COMPRESSOR INLET TEMPERATURE

The measured variable is intermediate pressure compressor discharge temperature and must be converted to high pressure compressor inlet temperature. It must also be corrected for humidity, specific heat, and inlet temperature.

$$\frac{T23}{\theta} = \left[\left(\frac{T23M + 459.7}{\theta} \times CPT23 \times CVPT23\right) - 60.9\right] \times 1.0926 \qquad (21)$$

CALCULATIONS OF PERFORMANCE VARIABLES

The following section presents the methods used to calculate some engine performance parameters from the temperatures, pressures, forces, and flows measured during the test. The engine parameters that can be calculated include: total engine airflow, engine core airflow, turbine inlet temperature, bypass ratio, overall compressor efficiency, overall turbine efficiency, overall compressor pressure ratio, overall turbine pressure ratio, engine pressure ratio, and specific fuel consumption.

Total Engine Airflow

The inlet bellmouth has static and total pressure probes which have readings displayed on the CRT and recorded on the line printer. The parameter, $\Delta P/\delta$ is calculated from the difference in these pressure readings and used to enter the curve in Figure 41 to yield engine total corrected airflow. (This curve is from the bellmouth manufacturer and is only good for bellmouth number 6872762 and screen number 7872166 or 67983644). This airflow must then be corrected for humidity and Cp effects as outlined earlier. The calculation of $\Delta P/\delta$ is:

$$\frac{\Delta P}{\delta} = \frac{P1 - PS1}{\frac{P1}{14.696}} \qquad (22)$$

Turbine Inlet Temperature and Engine Core Airflow

The calculation of turbine inlet temperature and engine core airflow is an iterative calculation using fuel flow, compressor discharge pressure and temperature (appropriately corrected), turbine inlet nozzle flow area, and some assumed burner performance parameters. For the calculations summarized in this appendix, burner pressure drop was assumed to be .055 and

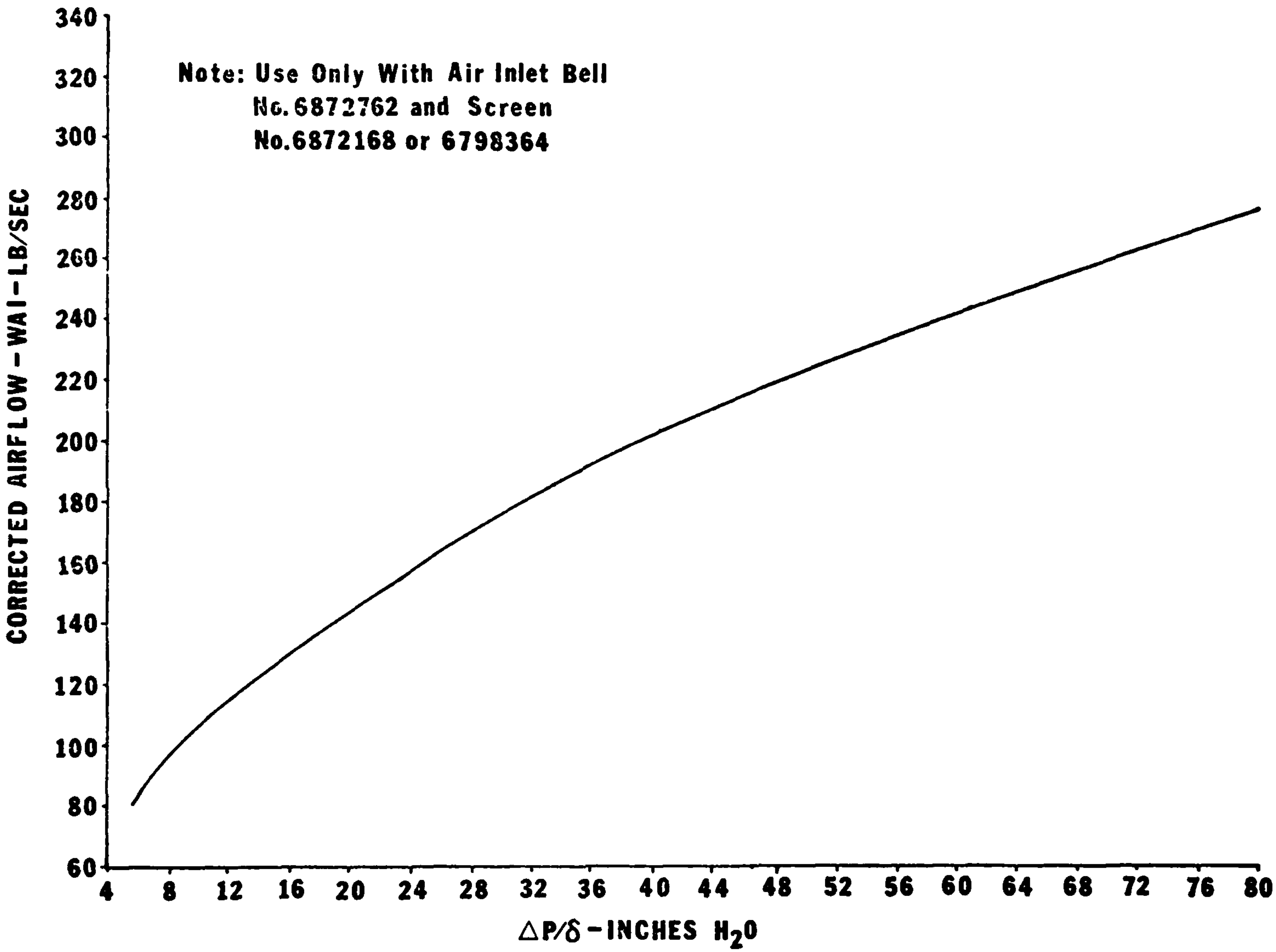


FIGURE 41 - INLET BELLMOUTH CHARACTERISTICS

burner efficiency was assumed at .999. The calculation procedure is as follows:

$$P4 = (1-\Delta P_B)P3 \tag{23}$$

Assuming that the turbine nozzle is choked:

$$\frac{WG4\sqrt{T4}}{P4 \quad A4} = .5312 \frac{\frac{LBM}{SEC}\sqrt{°R}}{LB_F} \tag{24}$$

Substituting equation (23) into equation (24) yields:

$$WG4\sqrt{T4} = .5312(A4) \quad (P3) \quad (1 - \Delta P_B) \tag{25}$$

The other governing equation in this case is the energy balance across the burner:

$$H4 = H3 + \eta_B\left(\frac{WF}{WA4}\right) \quad (LHV + 182. - HF4) \tag{26}$$

The procedure for solving these two simultaneous equations, noting:

$$WA4 = WG4 - WF \tag{27}$$

is to guess a T4 and calculate WG4 from equation (25). An H4 can then be calculated from equation (26). T4 can be obtained from the calculated H4 using thermodynamic tables. The entire procedure is then repeated until the guessed T4 and the T4 calculated from equation (26) are within 1°. When this interation converges, a solution is obtained for both T4 and WA4.

Before engine core airflow can be calculated, an estimate of the 11th stage customer bleed flow must be made. Assuming that the discharge port is choked and further assuming a 5% total pressure loss between compressor discharge and the bleed discharge and a 5% reduction in effective area, the estimated bleed flow rate is:

$$WBLEED = \frac{.532(.95xP3)\ (.95 \times ABLEED)}{\sqrt{T3}} \tag{28}$$

The engine core airflow (IP compressor inlet airflow) can then be calculated by adding the turbine cooling flow and the 11th stage bleed flow to the turbine inlet airflow and allowing .2% for leakage.

$$WA22 = \frac{WA4 + (.0604 \times WA4) + WBLEED}{.998} \qquad (29)$$

Bypass ratio can then be calculated using the results of equation (29) and the previously calculated engine total corrected airflow.

$$BPR = \frac{\frac{WA\sqrt{\theta}}{\delta}\left(\frac{\delta}{\sqrt{\theta}}\right) - WA22}{WA22} \qquad (30)$$

Overall Compressor Performance

The overall compressor pressure ratio can be calculated very simply by dividing the measured compressor discharge pressure (appropriately corrected for instrumentation, humidity and specific heat effects) by the engine inlet pressure.

$$OPR = \frac{P3}{PT} \qquad (31)$$

The overall compression system efficiency can be calculated, knowing the overall pressure ratio, engine inlet temperature and compressor discharge temperature (appropriately corrected) through the following equation:

$$\eta_C = \frac{H3I - H1}{H3 - H1} \qquad (32)$$

H1 and H3 can be determined from the appropriate thermodynamic tables as a function of T1 and T3. The ideal compressor discharge enthalpy can be calculated as a function of overall pressure ratio and engine inlet enthalpy.

$$H3I = f(OPR, H1) \qquad (33)$$

FAN TIP PERFORMANCE

The fan tip pressure ratio can be calculated very simply by dividing the measured fan tip pressure (appropriately corrected) by the engine inlet pressure.

$$PRFT = \frac{P21T}{PT} \qquad (34)$$

The fan tip efficiency can be calculated knowing the pressure ratio, engine inlet temperature and fan tip discharge temperature (appropriately corrected) through the following equation:

$$\eta_{FT} = \frac{H21TI-H1}{H21T-H1} \tag{35}$$

H1 and H21T can be determined from the appropriate thermodynamic tables as a function of T1 and T21T. The ideal fan tip discharge enthalpy can be calculated as a function of fan tip pressure ratio and engine inlet enthalpy.

$$H21TI = f(PRFT, H1) \tag{36}$$

FAN HUB PERFORMANCE

The fan hub pressure ratio can be calculated very simply by dividing the fan hub pressure (appropriately corrected) by the engine inlet pressure.

$$PRFH = \frac{P21T}{P1} \tag{37}$$

The fan hub efficiency can be calculated knowing the pressure ratio, engine inlet temperature and fan hub discharge temperature (appropriately corrected)) through the following equation:

$$\eta_{FH} = \frac{H21HI-H1}{H21H-H1} \tag{38}$$

H1 and H21H can be determined from the appropriate thermodynamic tables as a function of T1 and T21H. The ideal fan hub discharge enthalpy can be calculated as a function of fan hub pressure ratio and engine inlet enthalpy.

$$H21HI = f(PRFH, H1) \tag{39}$$

INTERMEDIATE PRESSURE COMPRESSOR PERFORMANCE

The intermediate pressure compressor pressure ratio can be calculated very simply by dividing the intermediate pressure compressor discharge pressure by the fan hub discharge pressure (both appropriately corrected).

$$PRIP = \frac{P22}{P21H} \tag{40}$$

The intermediate pressure compressor efficiency can be calculated knowing the pressure ratio, fan hub discharge temperature and intermediate pressure compressor discharge temperature through the following equation:

$$\eta_{IP} = \frac{H22I-H21H}{H22 - H21H} \tag{41}$$

H21H and H22 can be determined from the appropriate thermodynamic tables as a function of T21H and T22. The ideal intermediate pressure compressor enthalpy can be calculated as a function of intermediate pressure compressor pressure ratio and fan hub discharge enthalpy.

$$H22I = f(PRIP, H21H) \tag{42}$$

LOW PRESSURE COMPRESSOR PERFORMANCE

The low pressure compressor is made up of both the fan and the intermediate pressure compressor. The low pressure spool pressure ratio can be calculated by dividing the intermediate pressure compressor discharge pressure (appropriately corrected) by the engine inlet pressure.

$$PRLP = \frac{P22}{P1} \tag{43}$$

The low pressure compressor efficiency can be calculated knowing the pressure ratio, intermediate pressure compressor discharge temperature (appropriately corrected) and the engine inlet temperature through the following equation:

$$\eta_{LP} = \frac{H22I-H1}{H22 - H1} \tag{44}$$

H1 and H22 can be determined from the appropriate thermodynamic tables as a function of T1 and T22. The ideal low pressure compressor enthalpy can be calculated as a function of low pressure compressor pressure ratio and engine inlet enthalpy (equation (42)).

HIGH PRESSURE COMPRESSOR PERFORMANCE

The high pressure compressor pressure ratio can be simply calculated by dividing its discharge pressure by its inlet pressure (both appropriately corrected).

$$PRHP = \frac{P3}{P23} \tag{45}$$

The high pressure compressor efficiency can be calculated knowing the pressure ratio, and high pressure compressor inlet and discharge temperature through the following equation:

$$\eta_{HP} = \frac{H3I-H23}{H3-H23} \tag{46}$$

H23 and H3 can be determined from the appropriate thermodynamics tables as a function of T23 and T3. The ideal high pressure compressor enthalpy can be calculated as a function of high pressure compressor pressure ratio and inlet enthalpy.

$$H3I = f(PRHP, H23) \tag{47}$$

Overall Turbine Performance

The overall turbine pressure ratio can be calculated from the measured exhaust gas total pressure (appropriately corrected) and the turbine inlet pressure calculated in equation (23)).

$$TPR = \frac{P4}{P5} \tag{48}$$

The calculation of overall turbine efficiency is somewhat more complicated than the similar calculation for the compressor. First the turbine rotor inlet enthalpy must be calculated from the turbine nozzle cooling flow and the turbine inlet temperature calculated previously.

$$H41 = \frac{(WG4)\ (H4) + .0318\ (WA4)\ (H3)}{WG4 + .0318\ (WA4)} \tag{49}$$

Next, the untrimmed exhaust gas temperature must be calculated from the measured trimmed exhaust gas temperature (corrected for instrumentation, humidity, and specific heat effects) the T5 ballast resistance, the T5 thermocouple harness resistance and the T5 junction box temperature.

$$T5UT = T5M + \left(\frac{RH}{RES}\right)\ (T5M-TJB) \tag{50}$$

The turbine discharge enthalpy can be determined from the calculated temperature and fuel to air ratio using the appropriate thermodynamic table. The overall turbine efficiency can be calculated using the following equation.

$$\eta_T = \frac{H41 - H5}{H41 - H5I} \qquad (51)$$

The ideal turbine discharge enthalpy used in the above equation can be calculated as a function of overall turbine pressure ratio and turbine rotor inlet enthalpy.

$$H5I = f(TPR, H41) \qquad (52)$$

LOW PRESSURE TURBINE PERFORMANCE

There is no inter-turbine instrumentation so, in order to calculate low pressure turbine performance, several assumptions must be made. The most critical of these is that the low pressure turbine inlet nozzle remains choked over the region of interest. The TF41 production engine simulation (ref 7) predicts that the low turbine inlet nozzle flow function remains constant between intermediate and idle at sea level static conditions, lending some credibility to the choked flow assumption.

The work of the low pressure turbine must equal the work required to drive the low pressure compressor.

$$WLC \, \Delta HLC = WLT \, \Delta HLT \qquad (53)$$

$$(WA-WA22)(H21T-H1)+WA22(H22-H1)=(WA22+WF)(H43-H5) \qquad (54)$$

Rearranging and solving for the low pressure turbine inlet enthalpy yields

$$H43 = H5 + \frac{(WA - WA22)(H21T-H1)+WA22(H22-H1)}{WA22+WF} \qquad (55)$$

Making use of the appropriate thermodynamic table allows determination of low pressure turbine inlet temperature along with the choked flow assumption and the low turbine flow function from the TF41 simulation, yields the low pressure turbine inlet pressure.

$$P43 = \frac{(WA22+WF)\sqrt{T43}}{72.7} \qquad (56)$$

The low pressure turbine pressure ratio is simply the inlet pressure divided by the turbine discharge pressure.

$$PRLPT = \frac{P43}{P5} \qquad (57)$$

The low pressure turbine efficiency can be calculated knowing the pressure ratio, low turbine inlet temperature, and untrimmed turbine discharge temperature through the following equation:

$$\eta_{LPT} = \frac{H43-H5}{H43-H5I} \qquad (58)$$

H43 and H5 can be determined from the appropriate thermodynamics tables as a function of T43 ,T5UT and fuel to air ratio. The ideal low pressure turbine discharge enthalpy can be calculated as a function of pressure ratio, low turbine inlet enthalpy and fuel to air ratio.

$$H5I = f(PRLPT,H43,FAR) \qquad (59)$$

HIGH PRESSURE TURBINE PERFORMANCE

The high pressure turbine pressure ratio can be calculated using the inlet pressure calculated in equation(31)and the discharge pressure calculated by equation (56)

$$PRHPT = \frac{P4}{P43} \qquad (60)$$

The high pressure turbine discharge enthalpy can be calculated from the work balance with the high pressure compressor and allowing an additional 500 horsepower for gears, pumps, etc.

$$WA22(H3-H23)+(353/WA22)=(WG4+.0318WA4)(H41-H42) \qquad (61)$$

$$H42 = H41 - \frac{WA22(H3-H23)+(353/WA22)}{(WG4+.0318WA4)} \qquad (62)$$

The high pressure turbine efficiency can then be calculated knowing the pressure ratio and high pressure turbine inlet and exit enthalpies through the following equation:

$$\eta_{HPT} = \frac{H41 - H42}{H41 - H42I} \tag{63}$$

The ideal high pressure turbine discharge enthalpy can be calculated as a function of pressure ratio, high pressure turbine inlet enthalpy and fuel to air ratio.

$$H42I = f(PRHPT, H41, FAR) \tag{64}$$

Engine Pressure Ratio

The engine pressure ratio can easily be calculated from the measured exhaust gas pressure (appropriately corrected) and measured engine inlet pressure.

$$EPR = \frac{P5}{P1} \tag{65}$$

Engine pressure ratio is a very important parameter because it is directly related to both nozzle pressure ratio and thus thrust and is also generally very close to fan pressure ratio. This parameter is an excellent indicator of engine performance.

Specific Fuel Consumption

The engine's specific fuel consumption can easily be calculated using the results of equations (2) and (5).

$$SFC = \left(\frac{WF}{\sqrt{\theta}\delta}\right) \quad \sqrt{\theta}/\left(\frac{FG}{\delta}\right) \tag{66}$$

APPENDIX B LUBRICANT MONITORING/BORESCOPE REPORTS

MEMO FOR THE RECORD 14 Dec 1978

SUBJECT: 100 Hour Boroscope Inspection, TF41 S/N 142163

1. A hot section boroscope inspection of engine 142163 undergoing accelerated mission testing (AMT) at AFAPL's "D" Bay Sea Level Engine Test Facility was performed by Lab personnel on 8 Dec 1978. A Lab owned American Cystoscope Maker Inc. fiber optic boroscope was used for this inspection.

2. The engine was prepared for the inspection by Lab personnel. All fuel nozzles, HPT2 boroscope port plug, the left side intermediate case plugs, and the 7th and 11th stage bleed port covers were removed.

3. To date, engine 142163 had logged 108:47 hrs of operating time of which 100:44 hours was AMT time composed of 139 "A" cycles.

4. The fuel nozzles all exhibited moderate carbon buildup on the fuel spray nozzle aft faces. They were cleaned with a soft bristle brush and the internal passages were blown clean using very low pressure air. No outer air shroud burning or erosion was evident.

5. HPT1 vanes were in very good condition with no cracks or distortion noted. Several vanes displayed erosion of the surface coating on the leading edge near the root.

6. HPT1 blades were in good condition with no distress noted.

7. HPT2 vanes and blades all appeared to be in good condition. However, the particular boroscope used could only provide a limited viewing area.

8. All combustion liners appeared in good condition with only minor carbon deposits noted.

9. Igniter plugs displayed excessive erosion of the center electrode which was judged to be beyond T.O. limits. However, replacement plugs could not be located at this time so the original set was reinstalled on the engine.

10. A visual inspection up-the-tailpipe of the L.P. turbine area disclosed no evidence of operating distress or damage. There were no cracks noticed in the LPT bearing support fairing or struts. LPT2 blades exhibited a red deposit at the blade root. Two blended LPT2 vanes (at the 3 and 11 o'clock positions) were noticed during the initial inspection of the engine after delivery. No deterioration in their condition was noted at this time.

11. HPC blades and vanes were in good condition with no nicks or dents noted. However, considerable dirt buildup was seen.

12. The LPC and IPC blades and vanes were also in good condition but again were considered very dirty for the time operated.

13. No conditions were noted that would preclude further operation of engine 142163 on the present test program in "D" bay.

Robert J. May Jr.

ROBERT J. MAY
Aerospace Engineer
Performance Branch
Turbine Engine Division

Memo for the Record 3 January 1979

Subject: Borescope Inspection, TF41 S/N142163 Following Emergency Shutdown

1. A hot section borescope inspection of engine 142163 undergoing accelerated mission testing (AMT) at AFAPL's "D" Bay Sea Level Engine Test Facility was performed by Lab personnel on 14 Dec 78 after an emergency shutdown. A Lab owned American Cystoscope Maker Inc. fiber optic borescope was used for this inspection.

2. The engine was prepared for inspection by Lab personnel. All fuel nozzles, HPT2 borescope port plug, the left side intermediate case plugs, and the 7th and 11th stage bleed port covers were removed.

3. To date, engine 142163 had logged 148 hours of operating time of which 133 hours were AMT time, composed of 183+ "A" cycles.

4. The engine had been previously borescoped at 101 AMT hours and the findings were basically the same, with the following exceptions:

a) a very small crack in the #4 combustor can was discovered

b) some erosion of the trailing edges of 1st stage high pressure turbine vanes was noticed, especially behind the #4, 7, and 9 cans.

c) a possible small "dent" in the leading edge of a 1st stage high pressure turbine blade was noted.

5. There does not appear to be any unusual gas path damage. No conditions were noted during this inspection that would preclude further operation of this engine.

ROBERT J. MAY, Jr
Project Engineer

DEPARTMENT OF THE AIR FORCE
AIR FORCE AERO PROPULSION LABORATORY (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: SFL

19 Dec 78

SUBJECT: Analysis of Lubricant Samples from TF-41 AMT Engine, S/N AE142163 (OP-151)

TO: AFAPL/TBA (R. May)

1. Lubricant samples (0-69-2, MIL-L-7808) taken from an AMT TF41 (S/N AE142163) engine were periodically analyzed. The samples were coded as follows:

LAB SAMPLE NO.	DATE	HSOH	HSOC	REMARKS
OP-151-1	1 Dec	24:46	24:46	
-2	5 Dec	58:20	21:58	
-3	7 Dec	100:33	45:10	
-4	11 Dec	108:47	50:24	
-5	13 Dec	125:43	25:43 ?	
-6	13 Dec	147:30	89:07	
-7	14 Dec			after engine stop
-8	15 Dec			after motoring engine
-9	18 Dec	147:50		after 22 min run

2. Viscosity and total acid number data available to date are as follow:

LAB SAMPLE NO.	TAN (mg KOH/g)	VISC @ 100°F
OP-151-1	0.1	13.62
OP-151-2	0.1	13.69
OP-151-3	0.1	13.78

3. Spectrometric oil analysis (SOAP) data available are the following:

	TRACE WEAR METALS (ppm)											
LAB SAMPLE NO.	Fe	Ag	Al	Cr	Cu	Mg	Ni	Pb	Si	Sn	Ti	Mo
OP-151-1	1	0	0	0	2	0	0	0	4	5	0	0
-3	1	0	0	0	2	0	0	0	5	7	0	0
-4	1	0	0	0	2	0	0	0	6	9	0	0
-5	1	0	0	0	1	0	0	0	7	10	0	1
-6	2	0	0	0	1	0	0	0	7	5	0	0

4. Ferrographic analysis of each sample was completed. In the attached table, the quantities of individual types of wear debris are indicated by 0 = none, 1 = few, 2 = moderate, and 3 = heavy. The overall wear assessment made on the analytical form is also given.

5. Summary and conclusions: TAN and viscosities indicate that no significant lubricant degradation has occurred. SOAP data to date did not suggest any extraordinary wear. Two remaining analyses are to be made. Ferrographic data suggested that by sample OP-151-5 some surface fatigue was occurring (spheres). However, the amount of debris was not sufficient to predict a failure. Samples after the engine stopped all contained much more debris than earlier found and with a variety of wear types. The sample after the 22 minute run, OP-151-9, contained wear debris of a quantity and of types that indicated that the run should be terminated. It appeared that ferrous wear was continuing in the oil-wetted system. The types of wear debris found indicated that the problem was serious and that the source of the wear should be determined.

6. As soon as the final SOAP data are available, they will be forwarded.

PW Centers

P. W. CENTERS
Lubrication Branch
Fuels & Lubrication Division

1 Atch
Ferrographic Data

TABLE: FERROGRAPHIC DATA

		TYPES OF WEAR DEBRIS							
LAB SAMPLE NO	FERROGRAM NO	RUBBING	CHUNKS	SPHERES	LAMINAR	SEVERE	CUTTING	NON-FERROUS	OVERALL RATING
OP-151-1	319	1	1	1	0	1	1	0	normal
-2	322	1	2.5	1.5	0	1	1	1	caution
-3	323	1	1.5	1	1	0	0	0	normal/ caution
-4	324	1	1	1	1	0	0	0	normal/ caution
-5	325	1	2	2	1	1	0	0	caution
-6	326	1	1	2	0	0	1	1	caution
-7	327	2.5	2.5	2.5	2	2.5	1	0	caution/ alert
-8	328	3	2.5	1	3	2	2	1	caution/ alert
-9	329	2.5	2	1	2	2.5	2	0	caution/ alert

DEPARTMENT OF THE AIR FORCE
AIR FORCE AERO PROPULSION LABORATORY (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: SFL — 22 Dec 78

SUBJECT: Additional Analyses of Lubricant Samples from TF-41 AMT Engine, S/N AE 142163 (OP-151)

TO: AFAPL/TBA (R. May)

1. Analyses of the following additional sample has been obtained:

LAB SAMPLE NO.	TAN (mgKoH/g)	VISC @ 100°F
OP-151-9	0.10	13.58

2. Trace metals in those samples as reported by Rickenbacker AFB are as follow:

	TRAVE WEAR METALS											
LAB SAMPLE NO.	Fe	Ag	Al	Cr	Cu	Mg	Ni	Pb	Si	Sn	Ti	Mo
OP-151-8	0	0	0	0	0	0	0	0	5	10	0	0
OP-151-9	2	0	0	0	0	0	0	0	6	7	0	0

3. For sample identification, please refer to previous report on 19 Dec 78.

P. W. Centers

P. W. CENTERS
Lubrication Branch
Fuels & Lubrication Division

APPENDIX C TEARDOWN INSPECTION REPORTS

FORM 10550 REV 3/71

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 142163 T D 6 MODEL TF41 T D DATE 20 December 1978

INSPECTORS Duckett/Fattic/Toms TOTAL TIME ______ ENDURANCE TIME ______

REASON FOR T D ______

PARTS NOT LISTED ARE VISUALLY O K

PART NAME (P/N & S/N)	DEFECTS
Fairing Support Assy-LP Turbine P/N 6866791	Two fairings have cracks about 1" long at leading edge of struts.
Ring Assy-Retaining LP2 Nozzle P/N 6861039	Both rings have several large cracks; also several small cracks.
Seal Segments-LP1 Turbine P/N 6865635	Heavy rub spots in ID of all seal segments.
Rotor Assy-LP Turbine P/N 6867969	Heavy rub on shrouds of LP1 and LP2 blades. Heavy wear on seals on LP2 shaft.
Seal Seg-Stg 2 HPT P/N 6892966 - 13 pieces	Light to very heavy rub and pickup in ID.
Blade-HPT Stg 2 P/N EX126845	Blades have heavy rub on OD of outer shrouds.
Wheel & Shaft Assy-HPT Stg 1 P/N 6887655 Blades P/N 6869795	Foreign object damage on leading edge of four blades. Two blades, Positions 4 and 11, have holes at damage area.
Scoop Assy-Primary Air Comb P/N 6863363	Scoops not removed from Diffuser. Positions 1, 2 and 10 have cracks at rear mounting nut welds.
Seal Inner Rotor Disc HPT P/N 6894586, S/N FX17263	Heavy rub wear and burrs on air seals.
Vane Assy-HPT Stg 2	
P/N 6892950, Pos. 1, 4, 8 & 15	Cracks at cooling air holes.
Pos. 3	Cracks at cooling air holes to leading edge... center and end segments.
P/N 6894681, Pos. 10	Center and end segments have cracks from cooling air holes to leading edge of vane.
Pos. 5, 7, 14 & 19	Cracks at cooling air holes to leading edge.
Pos. 21	Crack at cooling air holes to leading edge center segment.
Liner & Nozzle Assy-Comb	
Pos. 1, P/N EX126821 Liner S/N SLF2037A Nozzle S/N SD2-2265	Three smoke chutes have heavy erosion. Nozzle has four large cracks on OD and two large cracks in ID. Heavy fretting on nozzle flanges.

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 142163 T.D. 6 MODEL TF41 T.D. DATE 20 December 1978

INSPECTORS ________ TOTAL TIME ________ ENDURANCE TIME ________

REASON FOR T.D. ________

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Liner & Nozzle Assy-Comb Pos. 2, P/N EX125312 Liner S/N SLB1355 Nozzle S/N SD4-1649	Four smoke chutes have heavy erosion. Four cracks in welds at crossover tubes. Heavy fretting on crossover tube and connector. Heavy fretting on nozzle flanges.
Nozzle Assy-Discharge Pos. 3, P/N 6897118, S/N SD1-9566	Three Cracks in nozzle; heavy fretting on nozzle flanges.
Nozzle Assy-Discharge Pos. 4, P/N 6897118, S/N ?	One crack in nozzle. Heavy fretting on nozzle flanges.
Nozzle Assy-Discharge Pos. 5, P/N 6897118, S/N ?	Crack in nozzle. Heavy fretting on flanges.
Liner & Nozzle Assy-Comb Pos. 6, P/N EX126822 Liner S/N SLF2107A Nozzle S/N ?	Two cracks at crossover tubes. Heavy fretting on crossover tube OD. Two large cracks in nozzle; heavy fretting on nozzle flanges.
Liner & Nozzle Assy-Comb Pos. 7, P/N EX125311 Liner S/N SLF320 Nozzle S/N SD5-5900	Two smoke chutes have heavy erosion. Two cracks at crossover tube. Heavy fretting on connector and crossover tube. Large hole in nozzle; heavy fretting on nozzle flanges.
Liner & Nozzle Assy-Comb Pos. 8, P/N EX126823 Liner S/N SLF3376 Nozzle S/N ?	Crack in weld at crossover tube. Heavy fretting on connector and crossover tube. Crack on OD and in ID of nozzle. Heavy fretting on nozzle flanges.
Liner & Nozzle Assy-Comb Pos. 9, P/N EX125311 Liner S/N SLF61 Nozzle S/N SD5-5382	Large hole burned in nozzle. Three smoke chutes have heavy erosion. Two cracks at crossover tube.
Liner & Nozzle Assy-Comb Pos. 10, P/N EX125312 Liner S/N SLF245A Nozzle S/N SD5-5784	Two cracks at crossover tube. Heavy fretting on crossover and connector. One smoke chute has heavy erosion; two have medium. Heavy fretting on nozzle flanges.
Igniter Assy-Spark P/N 6867778	Heavy erosion on both Igniters. They are out of limits and should be replaced.
Support & Seal Assy-HPT Brg P/N 6892649, S/N FX16791	Top Support strut is cracked.
Vane Assy-HPT Stg 1 P/N 6894686 - 20 pieces	Vanes were not removed from HPT Support. All vanes have cracks at trailing edge. Some have heavy erosion. Eleven vanes have cracks from leading edge to cooling air holes.

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 142163 T.D. 6 MODEL TF41 T.D. DATE 20 December 1978

INSPECTORS ________ TOTAL TIME ________ ENDURANCE TIME ________

REASON FOR T.D. ________

PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Plate-Stop LP1 Compressor Blades P/N 6866219	Plate broken; bolt holes torn. Bolts were still tight in plate.
Manifold Assy-Air Bleed Stg 7 P/N 6866550	OD of aft flange has worn spot 6" long at 5 o'clock position...bleed valve contact.
Valve Assy-Bleed HPC P/N 6867211	Rub wear in ID, forward area at splitline...manifold contact.
Compr Case & Vane Assy-HP P/N 6860894	Light to very heavy wear on ends of outlet guide vanes...very heavy at 7 to 8 o'clock area...approximately 1/16" wear from annulus piece and seal contact.
Annulus Piece & Seal Carrier P/N 6878080	Light to heavy outlet vane wear on OD. Annulus has a 2" crack from aft edge at 190° from top.
Bearing, Ball-HP Compr P/N 6863739	OD of inner races have light wear...separator contact. Separator has light to medium rub spots in ID.

This completes the report. Any additional information will be submitted as an addendum.

EXPERIMENTAL ASSEMBLY & TEST INSPECTION
TEARDOWN INSPECTION REPORT

UNIT 840 Stock 142163 T.D. 6 MODEL TF41 T.D. DATE 2-9-79

INSPECTORS Fisher-Fattic TOTAL TIME ENDURANCE TIME

REASON FOR T.D.

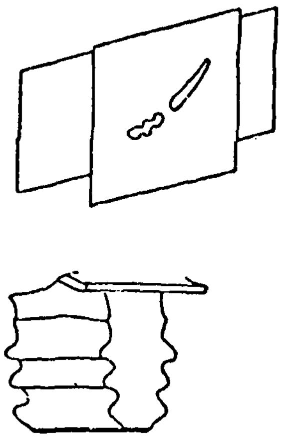
PARTS NOT LISTED ARE VISUALLY O.K.

PART NAME (P/N & S/N)	DEFECTS
Blade-Turb 2nd Stg. H.P. P/N EX131116	Zyglo-See attached charts for cracks.

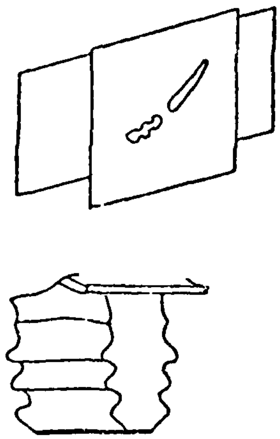
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 - Blade Asm, Rotor HPT Stg 2 Ref: 6892983

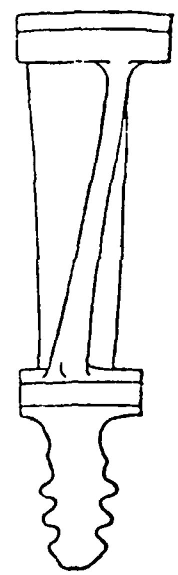
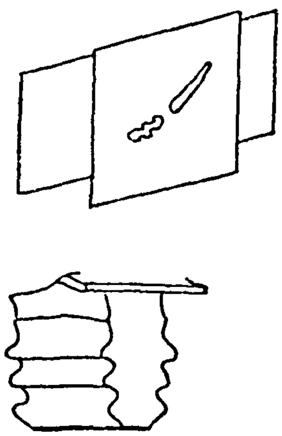
Unit 142163 T.D. 6 Inspector G. Kelly Date 2-8-79
From 840 Stock.



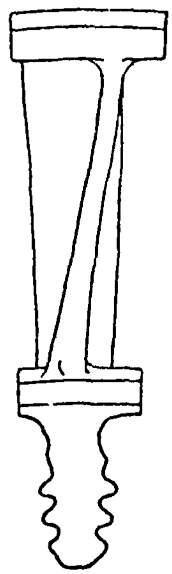
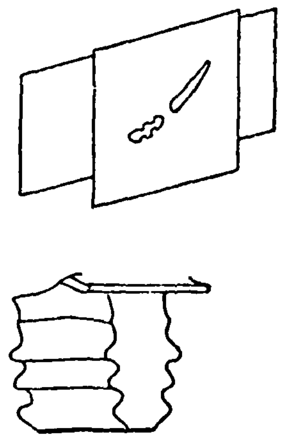
P/N EX131116
S/N ?
Pos. 25

P/N
S/N
Pos.

P/N
S/N
Pos.

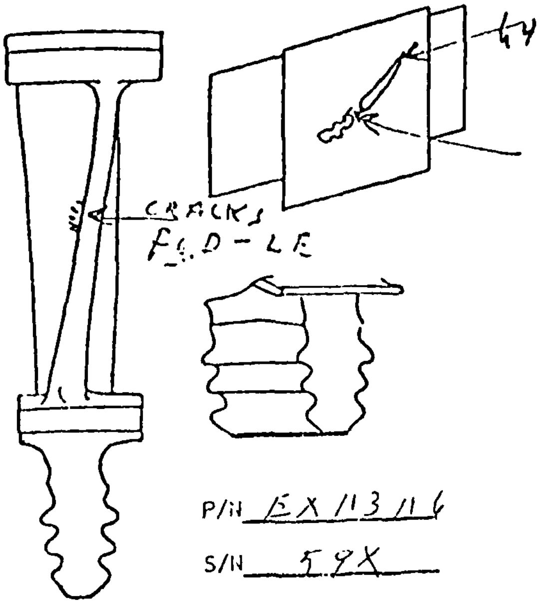
P/N
S/N
Pos.

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

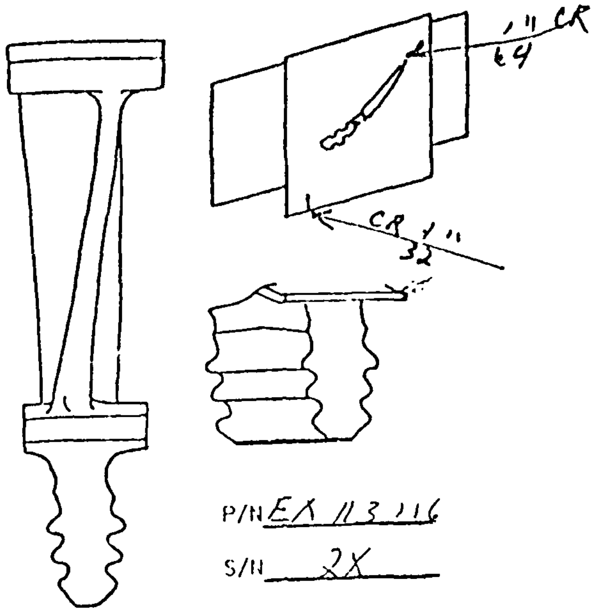
Ref: 6892983

TF41 - Blade Asm, Rotor HPT Stg 2

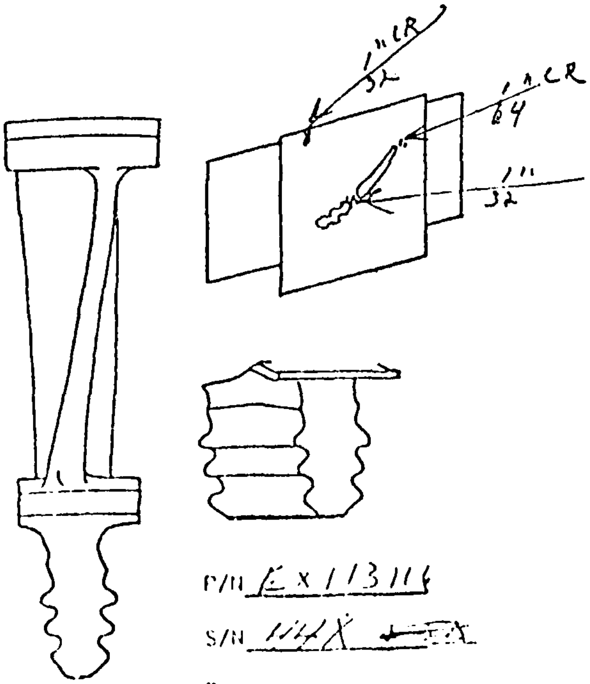
Unit 840 Stock T.D. ______ Inspector Falk Date 2-9-79
142163 - TD6



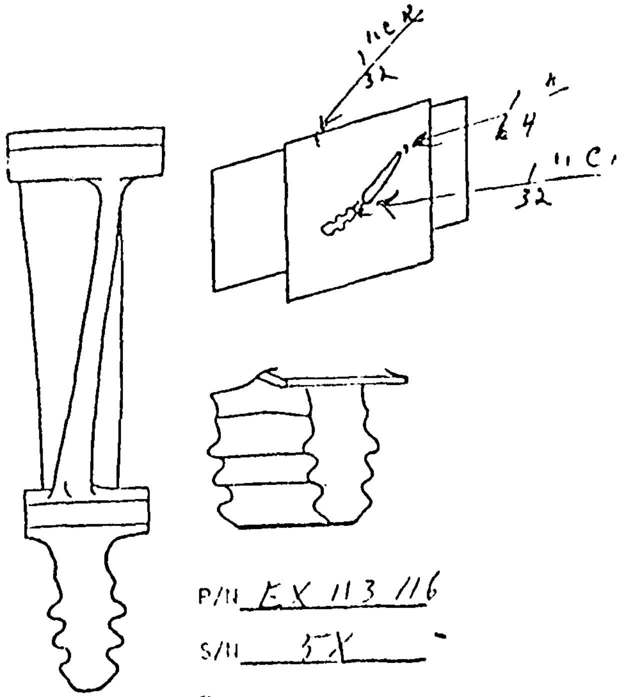
P/N EX 113116
S/N 59X
Pos. ________



P/N EX 113116
S/N 2X
Pos. ________



P/N EX 113116
S/N 114X
Pos. ________

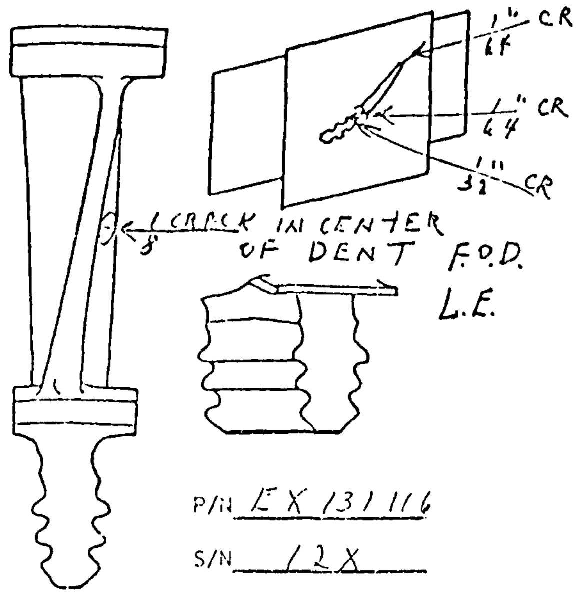


P/N EX 113116
S/N 5X
Pos. ________

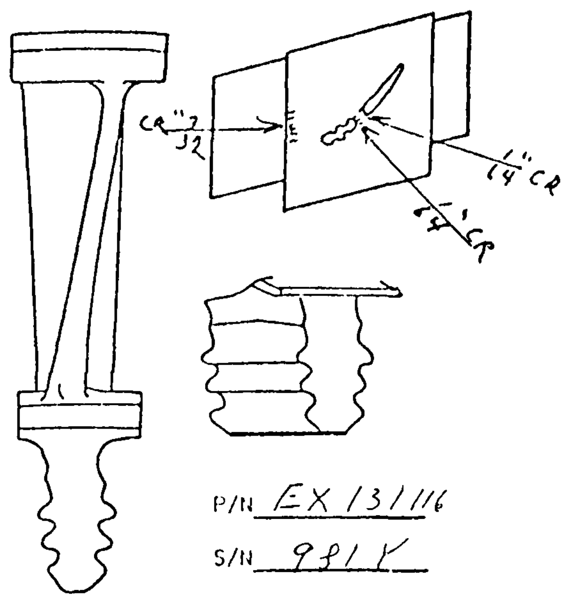
EXPERIMENTAL ASSEMBLY & TEST INSPECTION

TF41 - Blade Asm, Rotor HPT Stg 2 Ref: 6892983

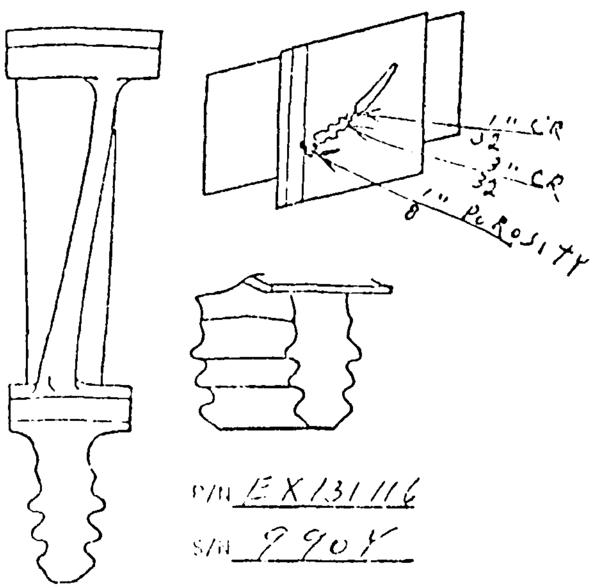
Unit 84c Stock T.O.______ Inspector ________ Date 2-9-79
142163 — TD 6



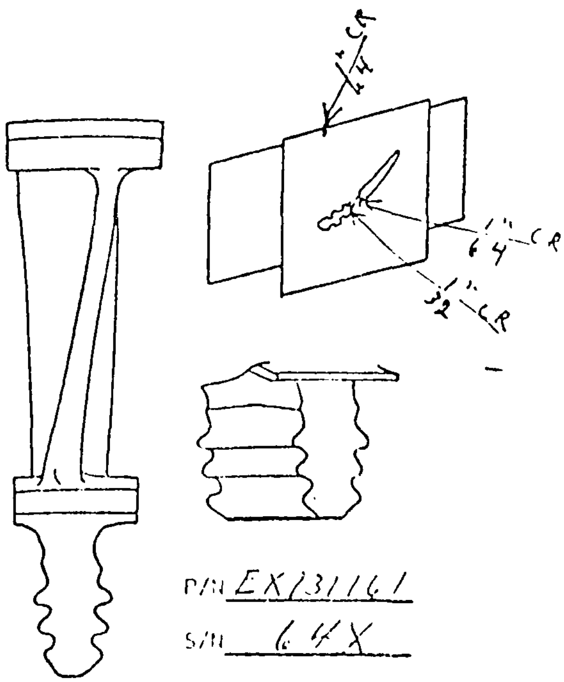
P/N EX 131116
S/N 12X
Pos.______



P/N EX 131116
S/N 981Y
Pos.______



P/N EX 131116
S/N 990Y
Pos.______



P/N EX 131161
S/N 64X
Pos.______

EXPERIMENTAL ASSEMBLY & TEST INSPECTION

S/N 142163/6C

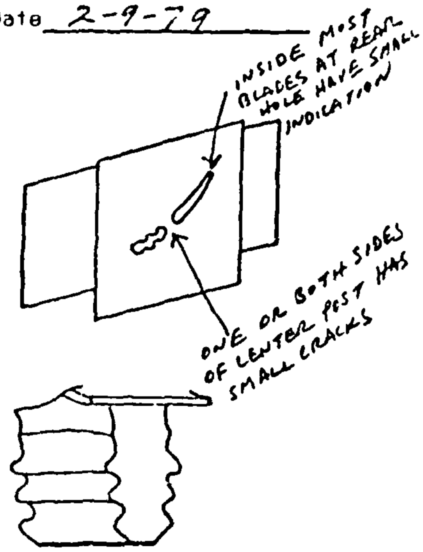
TF41 - Blade Asm, Rotor HPT Stg 2

Ref: 6892983

Unit 142163 T.D. 6 Inspector FISHER/FATTIC Date 2-9-79

BLADES FROM 840 STOCK

Position	S/N
ALL BLADES	S/N 976Y THRU
	999Y & 1X THRU
	70X
SEE SEPERATE	CHARTS
FOR OTHER	DEFECTS
	59X
	44X
	2X
	5X



P/N EX131116

APPENDIX D TEST PLAN

TEST PLAN

AIR FORCE AERO PROPULSION LABORATORY

22 NOV 1978

1. TITLE: TF41 Accelerated Mission Test (AMT).

2. JON: 30661602

3. PROJECT ENGINEER: Robert J. May, Jr. TBA 54830

4. PROJECT TEAM:

Mark Reitz	TBA	54830
Doretta Holland	TFIC	55636
Dave Chaffee	TBA	54830

5. CONFIGURATION: Engine Type - TF41-A-1

Serial Number - 142163

Special Features - Block 76 Hardware

#6 bearing cast support

HPT-1 bull nose vanes

#5 bearing rear seal deletion

HPC 4-5-6 Eiffel tower vanes

HPC-1 blades

fuel manifold

NL anticipator

HPT-1 lockplate damper

viton wills ring

- Several rework and repair schemes

- Air cooled second stage high pressure turbine blade

6. FACILITY: "D" stand, sea level engine test facility, AF Aero Propulsion Laboratory.

7. FUEL/LUBES: FUEL: MIL-T-5624, JP4

LUBE OIL: MIL-L-7808. See Hoover Smith, SFL, 54667 for a particular drum of MIL-L-7808 to be used for this test in D-Bay.

8. TEST OBJECTIVES:

8.1 Establish durability characteristics of a TF41 with "Block 76" modifications.

8.2 Document overall engine performance deterioration of a TF41 with "Block 76" hardware modifications and attempt to isolate major contributions to engine deterioration.

8.3 Document burner outlet temperature profile changes due to engine deterioration.

8.4 Demonstrate durability of several proposed reworks and repair schemes.

8.5 Demonstrate durability of aircooled second stage high pressure turbine blade.

9. INSTALLATION:

9.1 Install engine in "D" bay according to standard TF41 procedures.

9.2 Instrument as specified in instrumentation section of this plan.

9.3 Install tailpipe and exhaust nozzle.

9.4 Install TF41 airmeter bellmouth and screen.

9.5 Connect power lever to automatic throttle control and use standard throttle rigging. Refer TO 2J-TF41-6 for specific details.

9.6 Service engine with oil provided by SFL.

9.7 Take a 1 pint sample of oil (from oil drum) to SFL.

9.8 Provide bleed take-off pipe and variable size oriface plates for 11th stage HP compressor bleed port.

9.9 Recalibrate all instrumentation.

10. INSTRUMENTATION:

The following list describes the instrumentation requirements for the

AMT cyclic test on engine S/N 142163.

10.1 Engine inlet temperature.

10.2 Engine inlet pressure.

10.3 Bellmouth static pressure.

10.4 Low pressure rotor speed.

10.5 High pressure rotor speed.

10.6 Turbine outlet temperature.

10.7 Fuel flow.

10.8 Fuel inlet temperature.

10.9 Low pressure and intermediate pressure compressor discharge pressure (dual probe).

10.10 Low pressure and intermediate pressure compressor discharge temperature (dual probe).

10.11 High pressure compressor discharge static pressure.

10.12 High pressure compressor discharge temperature.

10.13 Fuel manifold pressures, pilot and main.

10.14 Low pressure turbine outlet pressure.

10.15 Low oil pressure.

10.16 Engine main oil pressure.

10.17 Low pressure cooling air outlet temperature.

10.18 Engine vibration.

front compressor (vertical) - front flange top

rear compressor (vertical) - fuel manifold boss, top

turbine (near vertical) - LP turbine oil tube boss, bottom

10.19 IGV position.

10.20 Power lever position.

10.21 Engine oil inlet temperature.

10.22 Engine thrust.

10.23 Temperature limiter amplifier current.

10.24 Junction box temperature.

10.25 Exhaust gas temperature rake.

10.26 Dry bulb temperature.

10.27 Wet bulb temperature.

11. SPECIAL REQUIREMENTS:

11.1 A once per second digital recording and storage capability is required for every engine and facility parameter measured and the status of every facility device used during this test.

11.2 Continuous recording of the following parameters on an oscillograph recorder is also required:

- turbine outlet pressure.
- turbine outlet temperature.
- high pressure rotor speed.
- low pressure rotor speed.
- fuel flow.
- temperature limiter amplifier current.
- power lever angle.
- oil inlet temperature.
- oil outlet temperature.
- main oil pressure.
- low oil pressure.
- fuel manifold pressure.
- fuel temperature.
- compressor vibrations.
- burner vibrations.
- turbine vibrations.

12. OPERATING LIMITS:

12.1 The engine operating limits are those applicable to any TF41 engine and are spelled out in TO 2J-TF41-6. The operating limits that are entered in the control computer should be coordinated with the TF41 test project team.

12.2 Once the engine and facility limits have been determined and the data base has been prepared and loaded into the control computer, a very careful check of the high and low limits should be carried out by the project engineer and facility engineer.

13. STANDARD PROCEDURES:

This test will be conducted according to "D" bay standard operating and emergency procedures as outlined in the operator's manual. The TF41 prestart checklist will be complied with before the initial start of each shift. In addition, the following procedures will be followed:

13.1 Record all start and stop data including reasons for shutdown.

13.2 No control system or operating limit adjustments shall be made during this test without the specific approval of the project engineer or other team member in his absence.

13.3 Take care to note in the engine log all incidents of the run such as overspeeds, overtemperature, leaks, vibrations, irregular functioning of the engine, facility or instrumentation, smoking or sparking and describe any corrective action taken.

13.4 Daily record specific gravity of the fuel and reference temperature in the engine log.

13.5 Oil servicing shall be in accordance with current TF41-A-1 instructions. Maintain daily log of oil added and oil consumption during the entire test.

13.6 Log all maintenance, planned inspections, boroscope inspections, etc.

13.7 The low pressure compressor and intermediate pressure compressor pressure and temperature instrumentation should be removed during the cyclic testing portion of this test. This instrumentation should be installed only during power calibrations.

13.8 The exhaust gas temperature rake should be installed in the tailpipe only during power calibrations and not during cyclic testing.

13.9 Turn on data logger just before the 6 minutes flat at intermediate power near the end of each "A" cycle.

13.10 Record T4, T1, LPC and T5.1 at the end of the 6 minute flat at intermediate power near the end of each "A" cycle.

13.11 Power calibration and exhaust gas surveys should be run with the 11th stage bleeds blocked off.

13.12 The engine should be allowed to stabilize 5 minutes before recording power calibration data.

13.13 The desired tolerance on speed settings during the "automatic" portion of the test shall be $\pm$ 50 rpm HN ($\pm$ 0.4%).

13.14 Once every four hours measure and record dry bulb and wet bulb temperature and look up vapor pressure from the appropriate curve.

13.15 Check oil level as often as necessary as dictated by engine oil consumption.

13.16 Monitor starter oil temperature during all motoring of the engine. The starter oil temperature should not exceed 250°F.

13.17 Thoroughly wash inlet FOD screen when total pressure drop exceeds 8 inches of H2O.

13.18 Rotor coast-down speeds need only be recorded when the oil level is to be checked or at least once per shift.

13.19 Maintain a log of total engine time, total AMT time, and the number and types of cycles that have been run.

13.20 Insure that the data acquisition and storage system is operating properly. (Specific instructions to be provided.)

13.21 EGT survey can be run with only 1/2 the number of tailpipe bolts as normal.

14. INITIAL ENGINE/FACILITY CHECKOUT:

The following procedures should be followed during the initial running of the engine after installation in the test cell:

- motor the engine for at least 30 seconds on the starter.
- start the engine and stabilize at idle for 5 minutes.
- check all instrumentation readings.
- if the facility and engine operation appear normal perform a walk around inspection, checking for leaks, loose fittings, etc.
- if there are no discrepancies make a slow accel to 85% NH and stabilize, checking all engine and facility parameters.
- if the facility and engine operation appear normal, slowly accel to 90% NH, stabilize, and check all engine and facility parameters.
- if the facility and engine operation appear normal, slowly accel to intermediate power, stabilize, and check all engine and facility parameters.
- perform a slow decel to idle and stabilize.
- if the facility and engine operation appear normal, perform a snap accel to intermediate, stabilize, and then a snap decel to idle.

- if no engine or facility discrepancies have been discovered up to this point, continue with the test plan performing the engine functional checks described in the following section. If problems have been identified shut down, make the necessary repairs, and then complete the remaining steps of this section.

15. ENDURANCE TEST:

The engine will be trimmed and set up before delivery to AFAPL by Allison. Mass flow limiter may need to be reset to better meet test objectives.

15.1 Engine Functional Check (initially and every 100 hours thereafter) see TO 2J-TF41-6, para 10-35 and Table 10-4.

15.1.1 Check IGV ram closing schedule. Determine that the attached schedule is satisfied (IGV - $+33^{o}$ and +7).

15.1.2 Check NL governor with pulldown tool according to TO 2J-TF41-6, para 10-63.

15.1.3 Check T5.1 pulldown according to TO 2J-TF-41-6, para 10-66.

15.1.4 Check P3 limiter according to TO 2J-TF41-6, para 10-64.

15.1.5 Check NH governor according to TO 2J-TF41-6, para 10-59, 10-60, 10-62.

15.1.6 Check ACU and DCU according to TO 2J-TF41-6, para 10-70, 10-71, 10-72, 10-73.

15.1.7 Check mass flow limiter using the T1 simulator and according to TO 2J-TF41-6, para 10-60.

15.2 High pressure rotor speed and power lever calibration with bleed (initially and every 100 hours).

15.2.1 Stabilize 5 minutes at each NH speed listed

80% ± .2%

85% ± .2%

88% ± .2%

90% ± .2%

94% ± .2%

15.2.2 Plot NH (rpm) versus power level angle. Determine power lever angle corresponding to the following speeds and provide this information for input into the automatic throttle control.

NH (rpm)	%rpm	PLA
10,332	80	
10,589	82	
10,977	85	
11,235	87	
11,364	88	
11,632	90	
12,010	93	
12,140	94	
12,269	95	

15.3 Performance calibration (initially and every 100 hours)

15.3.1 Blank off bleed ports

15.3.2 Install low pressure compressor and intermediate pressure compressor discharge pressure instrumentation.

15.3.3 Stabilize for 5 minutes at the following levels of corrected thrust and record 3 data points:

8,500 ± 200 LBS

10,500 ± 200 LBS

$12{,}500 \pm 200$ LBS

$14{,}500 \pm 200$ LBS

INTERMEDIATE

15.3.4 Remove low pressure compressor and intermediate pressure compressor discharge pressure instrumentation and replace with temperature instrumentation.

15.3.5 Repeat section 15.3.3.

15.4 Exhaust gas temperature survey

15.4.1 Blank off bleed ports.

15.4.2 Install thermocouple rake.

15.4.3 Stabilize for 5 minutes at intermediate power and record 2 data points.

15.4.4 Return to idle power, move 9 thermocouple connections to the 9 outside thermocouples on the rakes (that were not being used previously) and repeat section 15.4.3.

15.4.5 Shut down.

15.4.6 Rotate tailpipe one bolt hole and repeat.

15.4.7 Repeat twice until a total of 4 sets of data have been obtained.

15.5 Scheduled Inspections

15.5.1 Perform engine boroscope inspection of the hot section after each 100 hours of AMT testing.

15.5.2 Standard field service inspections shall be made and documented throughout the test. Reference TF41 Service and Operation Manual, Allison Publication Nr 1F2, 1 March 1974, Section 7.

- conduct 50 hours phase inspection
- conduct 100 hours phase inspection

- conduct 150 hours phase inspection.

- conduct 200 hours phase inspection.

15.5.3 Take two 1 pint oil samples immediately after initial servicing and at approximately 25 test hour intervals thereafter. The container will be provided by and the samples should be sent to SFL, Hoover Smith, 54667. SOAP and ferrograph analyses should be run.

15.6 Cyclic testing

15.6.1 The actual test consists of running the engine through a specified number of test cycles, labeled the "A", "B", and "C" cycles. A detailed description of these cycles is included on the attached pages. The test consists of 15 blocks made up of 20 "A" cycles, 4 "B" cycles, and 1 "C" cycle each.

15.6.2 The 11th stage bleed should be set at approximately 1.5 LBm/sec minimum (.62" diameter orifice plate). However, bleed will be varied in order to maintain higher turbine inlet temperatures on cold days. Coordinate bleed requirements with the project engineer.

15.6.3 Remove high pressure compressor and intermediate pressure compressor instrumentation.

15.6.4 Remove exhaust gas survey rake.

15.6.5 Enter "A" cycle into autothrottle and run 20 cycles.

15.6.6 Enter "B" cycle into autothrottle and run 4 cycles.

15.6.7 Enter "C" cycle into autothrottle and run 1 cycle.

NOTE: The sequence of "A", "B", and "C" cycles is relatively insignificant. The number of each type of cycle run is important. The sequence may be altered to better fit available test time and conditions.

15.6.8 Repeat 14.7.5 - 14.7.7, 14 times performing the required inspections and calibrations etc. Run 5 extra "A" cycles. (This

makes for approximately 263 hours of AMT testing).

15.6.9 Upon completion of 263 hours of cyclic testing, remove the engine and return to Allison for a teardown inspection.

CYCLE A

FLIGHT OPERATION

TIME (Min:Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
0:00	:30	Start Engine and accel to 55%	
0:30	2:00	Engine at Idle pwr	
2:30	:30	Accel to 90% N_H Dbl. datum on	
3:00	2:30	Accel to Intermediate Dbl Datum on	
5:30	1:00	Decel to 85% N_H, Dbl Datum Off	
6:30	2:00	Accel to Intermediate (100% N_H)	
8:30	:30	Decel to 90% N_H	
9:00	:15	Decel to 55% N_H	
9:15	:10	Accel to Intermediate	
9:25	:25	Decel to 93% N_H	
9:50	3:48	Accel to Intermediate, then Decel to 94% (19 Times). Each transient will take 6 sec.	
13:38	:12	Accel to Intermediate, transient to take 6 sec.	
13:50	:30	Decel to 88% N_H	
14:20	:08	Accel to Intermediate	
14:28	:15	Decel to 55% N_H	
14:43	:45	Accel to Intermediate	
15:23	:30	Decel to 88% N_H	
15:53	:08	Accel to Intermediate	
16:06	:15	Decel to 55% N_H	
16:21	:45	Accel to Intermediate	
17:06	:30	Decel to 88% N_H	
17:36	:08	Accel to Intermediate	
17:44	:07	Decel to 85% N_H	
17:51	:35	Accel to Intermediate	
18:26	:15	Decel to 90% N_H	
18:41	:08	Accel to Intermediate	
18:49	:07	Decel to 85% N_H	
18:56	:35	Accel to Intermediate	
19:31	:15	Decel to 90%	

CYCLE A

FLIGHT OPERATION

TIME (Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
19:46	:08	Accel to Intermediate	
19:54	:07	Decel to 85% N_H	
20:01	:35	Accel to Intermediate	
20:36	:15	Decel to 90% N_H	
20:51	:08	Accel to Intermediate	
20:59	:07	Decel to 85% N_H	
21:06	:35	Accel to Intermediate	
21:41	:15	Decel to 90% N_H	
21:56	:08	Accel to Intermediate	
22:04	:15	Decel to 55% N_H	
22:19	:35	Accel to Intermediate	
22:54	:30	Decel to 88% N_H	
23:24	:08	Accel to Intermediate	
23:32	:15	Decel to 55% N_H	
23:47	:35	Accel to Intermediate	
24:22	:30	Decel to 88% N_H	
24:52	:08	Accel to Intermediate	
25:00	:15	Decel to 55% N_H	
25:15	:35	Accel to Intermediate	
25:50	1:00	Decel to 88% N_H	
26:50	:08	Accel to Intermediate	
26:58	:07	Decel to 85% N_H	
27:05	:35	Accel to Intermediate	
27:40	:15	Decel to 90% N_H	
27:55	:08	Accel to Intermediate	
28:03	:07	Decel to 85% N_H	

CYCLE A

TIME (Min : Sec)		ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
28:10	:30	Accel to Intermediate	
28:40	:15	Decel to 90% N_H	
28:55	:08	Accel to Intermediate	
29:03	:07	Decel to 85% N_H	
29:10	:30	Accel to Intermediate	
29:40	:25	Decel to 90% N_H	
30:05	:15	Decel to 55% N_H	
30:20	:10	Accel to Intermediate	
30:30	:05	Decel to 88% N_H	
30:35	6:00	Accel to Intermediate	
36:35	:15	Decel to 55% N_H	
36:50	1:10	Accel to Intermediate	
38:00	:05	Decel to 80% N_H	
38:05	:05	Accel to 87% N_H	
38:10	:05	Decel to 80% N_H	
38:15	:05	Accel to 90% N_H	
38:20	:15	Decel to 55% N_H	
38:35	:30	Accel to Intermediate	
39:05	:05	Decel to 82% N_H	
39:10	:05	Accel to 90% N_H	
39:15	:15	Decel to 55% N_H	
39:30	:30	Accel to Intermediate	
40:00	:05	Decel to 82% N_H	
40:05	:05	Accel to 90% N_H	
40:10	3:19	Decel to 55% N_H	
43:29		Shutdown engine	
45:29		Motor Engine on Starter	
47:59		Start Engine and Accel to Idle	
48:29		Engine at Idle Pwr Ready for Next Cycle	

TOTAL CYCLE ENDURANCE TIME: 43 Min. 29 Sec.

CYCLE B

FLIGHT LINE OPERATION

TIME (Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
0:00	3:00	Engine at Idle Pwr	
3:00		Shutdown Engine	
5:00		Motor Engine on Starter	
7:30	:30	Start Engine and Accel to Idle Pwr	
8:00	3:00	Engine at Idle Pwr	
11:00		Shutdown Engine	
13:00		Motor Engine on Starter	
15:30	:30	Start Engine and Accel to Idle Pwr	
16:00	3:00	Engine at Idle Pwr	
19:00		Shutdown Engine	
21:00		Motor Engine on Starter	
23:30	:30	Start Engine and Accel to Idle Pwr	
24:00		Engine at Idle Pwr Ready for Next Cycle (A or C depending on schedule).	

TOTAL CYCLE ENDURANCE TIME 10 Min 30 Sec

CYCLE C

GROUND OPERATION
SFE TEST CYCLE SEQUENCE

TIME (Hr : Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR A CIT CONDITIONS
0:00:00	3:00	Engine at Idle Pwr	
0:03:00	3:15	Accel to Intermediate (No DD)	
0:06:15	3:00	Decel to Idle Pwr	
0:09:15	3:15	Accel to Intermediate	
0:12:30	3:00	Decel to Idle Pwr	
0:15:30	3:15	Accel to Intermediate	
0:18:45	3:00	Decel to Idle	
0:21:45	3:15	Accel to Intermediate	
0:25:00	3:00	Decel to Idle	
0:28:00	3:15	Accel to Intermediate	
0:31:15	3:00	Decel to Idle	
0:34:15	3:15	Accel to Intermediate	
0:37:30	3:00	Decel to Idle	
0:40:30	3:00	Accel to 95%	
0:43:30	3:00	Decel to Idle	
0:46:30	3:00	Accel to 95%	
0:49:30	3:00	Decel to Idle	
0:52:30	3:00	Accel to 95%	
0:55:30	3:00	Decel to Idle	
0:58:30	3:00	Accel to 95%	
1:01:30	3:00	Decel to Idle	
1:04:30	3:00	Accel to 95%	
1:07:30	3:00	Decel to Idle	
1:10:30	3:00	Accel to 90%	
1:13:30	3:00	Decel to Idle	
1:16:30	3:00	Accel to 90%	

CYCLE C

GROUND OPERATION
SFE TEST CYCLE SEQUENCE

TIME (Hr : Min : Sec) ELAPSED	AT	ACTION @ 66° CIT	P/L (CALIBRATION CURVE) THROTTLE FOR ALL CIT CONDITIONS
1:19:30	3:00	Decel to Idle	
1:22:30	3:00	Accel to 90%	
1:25:30	3:00	Decel to Idle	
1:28:30	3:00	Accel to 90%	
1:31:30	3:00	Decel to Idle	
1:34:30	3:15	Accel to Intermediate	
1:37:45	3:00	Decel to Idle	
1:40:45	3:15	Accel to Intermediate	
1:44:00	3:00	Decel to Idle	
1:47:00	3:15	Accel to Intermediate	
1:50:15	3:00	Decel to Idle	
1:53:15	3:15	Accel to Intermediate	
1:56:30	3:00	Decel to Idle	
1:59:30	3:00	Accel to Intermediate	
2:02:45	3:15	Decel to Idle	
2:05:45		Shutdown Engine	
2:07:45		Motor Engine on Starter	
2:09:45		Start and Accel to Idle Pwr	
2:10:15	:30	Engine at Idle Pwr Ready for Next Cycle	

TOTAL CYCLE ENDURANCE TIME 2 Hrs 6 Min 15 Sec

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